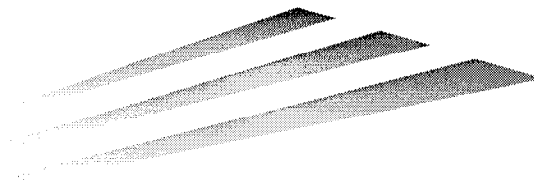# KENTUCKY

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CENTER

College of Engineering

Results of Creep Tests on Concrete

Cylinders for the Cable-Stayed Bridge

at Owensboro, Kentucky

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Report No. KTC-00-12

Results of Creep Tests on Concrete Cylinders for the Cable-Stayed Bridge at Owensboro, Kentucky

By

Daniel L. Eaton

and

David L. Allen, P.E., P.G.

Kentucky Transportation Center
College of Engineering
University of Kentucky
Lexington, Kentucky 40506-0281

in cooperation with

Kentucky Transportation Cabinet
Commonwealth of Kentucky

June 2000

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Introduction

The Kentucky Transportation Center was requested by the Kentucky Transportation Cabinet to conduct creep tests on the concrete from the new cable-stayed bridge over the Ohio River at Owensboro. The tests have been completed and the data is included herein.

Test Methods and Results

The creep tests were performed on cylinders according the ASTM C-512 (*Creep of Concrete in Compression*). In order to perform the creep tests the compressive strength of the cylinders must be determined. This was determined according to ASTM C-39 (*Compressive Strength of Cylindrical Concrete Specimens*). The modulus of elasticity was determined for one series according to ASTM C-469 (*Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression*). Three cylinders were loaded three days (3-day tests) after the cylinders were made, and three cylinders each were loaded at 30 days (30-day tests) and 90 days (90-day tests) after the cylinders were made. All of the tests ran for 180 days after loading.

Results of the 3-day tests, 30-day tests, and 90-day tests are listed in Sections 1, 2 and 3, respectively. Section 4 lists the results of the modulus and Poisson's ratio tests for the cylinders at 3 days. Section 5 lists the dimensions and weight of the cylinders. Section 6 lists the ASTM standard test methods referenced above. No analysis was performed on the data as the purpose of the tests was only to provide baseline data for future reference, if necessary.
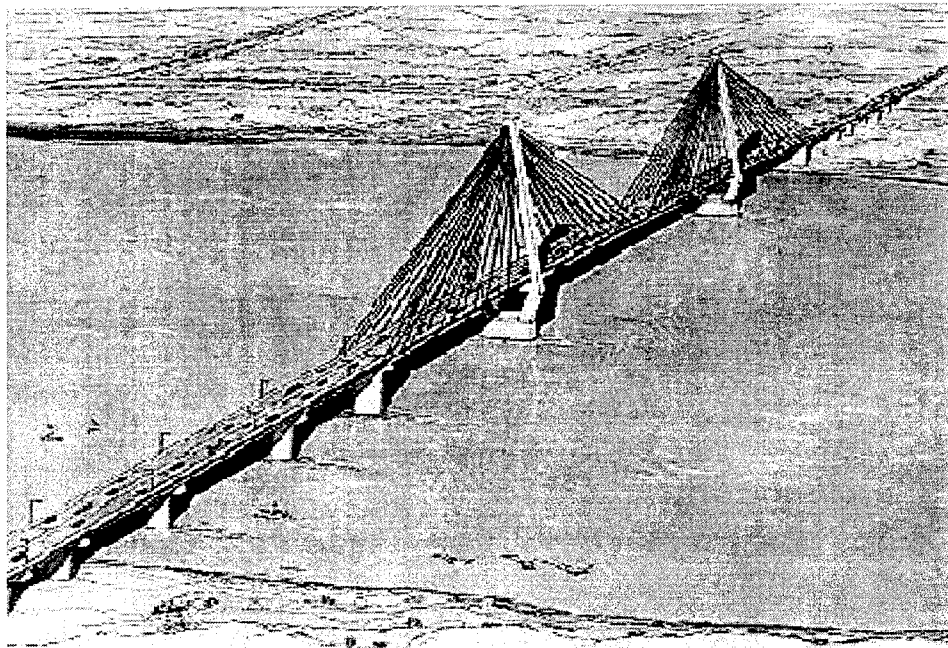
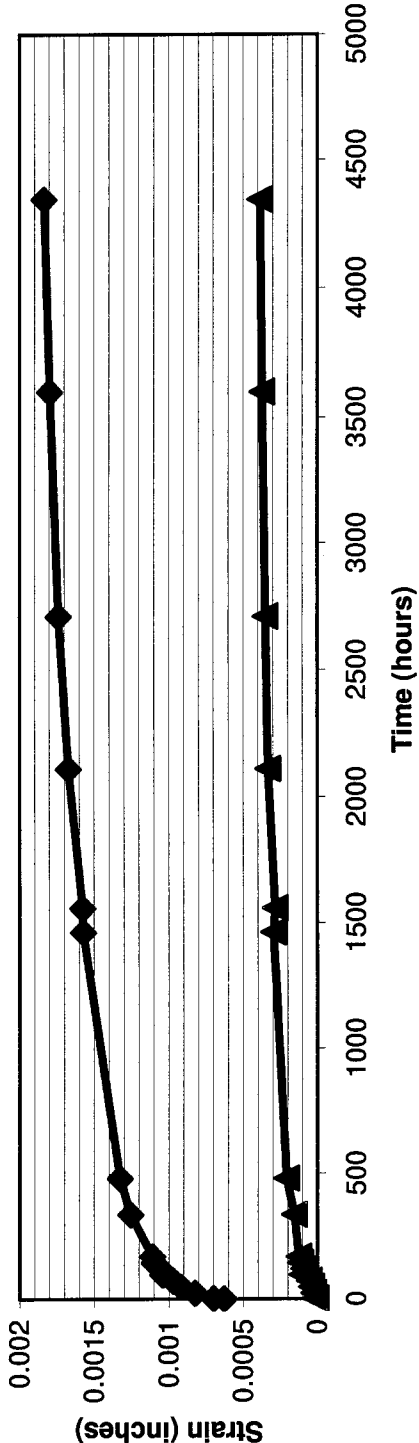**Virtual Image of Cable-Stayed Bridge, Owensboro**

Section 1

3-Day Creep Data

Strain values for 3-day samples. Average strain consists of 90 readings. 9 sets of tabs read ten times.
The Average for the Control Samples consists of 90 readings. 9 sets of tabs read ten times.

All measurements read in inches

											Control Samples	Avg. Strain
after loading	1	0.000416971	0.000669554	0.000703806	0.000470842	0.000882457	0.000654385	0.000549679	0.000699331	0.000611967	6.81698E-06	0.000628777
3-hour	3	0.000476621	0.000765287	0.00078583	0.000519015	0.000982802	0.000727222	0.000612155	0.00075436	0.000666453	1.14667E-05	0.000698861
1-day	24	0.000566668	0.000905159	0.000916611	0.000619378	0.001141059	0.000856838	0.000737681	0.00087703	0.000786323	2.4146E-05	0.000822972
2-day	48	0.000664458	0.001033854	0.000963359	0.000751569	0.001252585	0.000911609	0.00087897	0.000976484	0.000818155	3.9531E-05	0.000916782
3-day	72	0.000710629	0.001095478	0.001024447	0.000789706	0.001310784	0.000956056	0.000936574	0.001027214	0.000863751	5.42159E-05	0.000968293
4-day	96	0.000769418	0.0011743	0.001087256	0.000872003	0.001411989	0.001037783	0.001009655	0.001096287	0.000922539	0.000103304	0.001042359
5-day	120	0.000777161	0.001177453	0.001095	0.000888922	0.001426037	0.001046672	0.001021978	0.001114343	0.000950356	9.1995E-05	0.001055325
6-day	144	0.000821898	0.001227325	0.001142609	0.000927346	0.001481656	0.001090833	0.001046554	0.00114759	0.000979606	0.000114167	0.001098267
7-day	168	0.000825913	0.001241656	0.001150065	0.000934801	0.001491978	0.001107465	0.001075857	0.001161921	0.000987062	0.00012506	0.001108524
14-day	336	0.000930299	0.001394714	0.001294039	0.001074161	0.001671451	0.001263463	0.001221444	0.001308666	0.001120123	0.000153984	0.001253151
21-day	480	0.000995971	0.001486147	0.001361437	0.001143841	0.001765201	0.001334292	0.001285354	0.001375446	0.001183499	0.000205621	0.001325688
61-day	1464	0.001172624	0.001766465	0.001604642	0.001368079	0.002104652	0.001579185	0.001510613	0.001631676	0.001398003	0.000293157	0.00157066
2 month or 65 day	1560	0.001186676	0.001778217	0.001610092	0.001371233	0.002107805	0.001580045	0.001513765	0.001634256	0.001406893	0.000283443	0.001576554
3-month	2112	0.001265826	0.001881975	0.001716781	0.00146586	0.002229365	0.001685573	0.001607767	0.001725398	0.001479159	0.000331479	0.001673078
4-month	2712	0.001315725	0.001950765	0.001778045	0.001526078	0.002313081	0.001752101	0.001671963	0.001794758	0.00154569	0.000348808	0.001738957
5-month	3600	0.001356447	0.002014395	0.001829206	0.001586295	0.002393357	0.001812894	0.001734439	0.001848641	0.001593294	0.000371871	0.001796552
6-month	4344	0.00139086	0.002060255	0.001875094	0.001620705	0.002439229	0.001858776	0.001763098	0.001883034	0.001627706	0.000385251	0.001835417

Average Strain of Loaded Samples and Shrinkage of Control Samples vs. Time for 3-day Samples

Legend: Avg. Strain; Control Samples

Y-axis: Strain (inches) — 0, 0.0005, 0.001, 0.0015, 0.002
X-axis: Time (hours) — 0, 500, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000

Total Load-Induced Strain per pound per square inch

Measurements are defined as in section 8 of A.S.T.M. C 512 difference between the average strain values of the loaded and control specimens divided by the average stress.

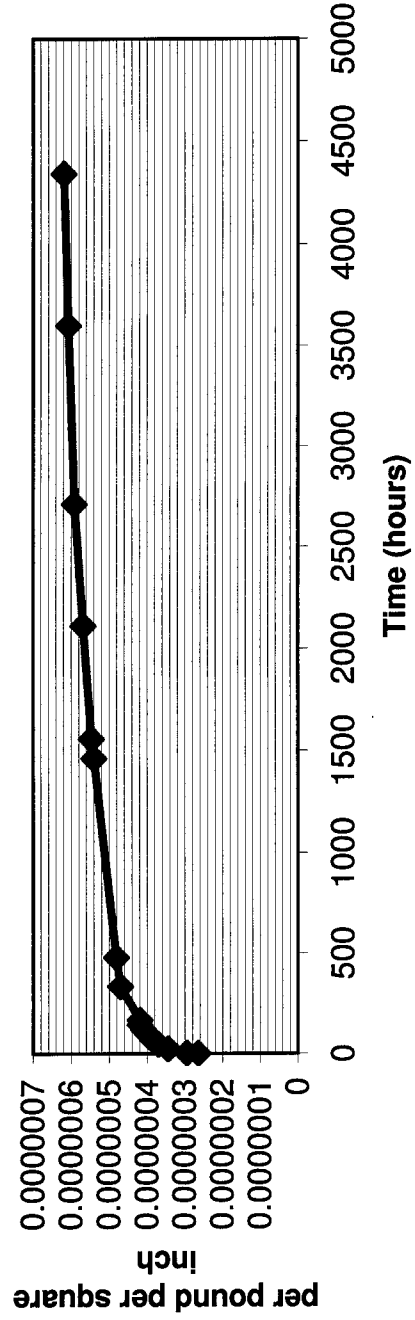Area of Cylinder   28.367 inches

Total Load-Induced Strain per pound per square inch

		Average Load	Average Stress										
after loading	1	66495	2344.097014	1.75E-07	2.827E-07	2.973E-07	1.98E-07	3.736E-07	2.763E-07	2.316E-07	2.954E-07	2.582E-07	2.6533E-07
3-hour	3	66095	2329.996122	1.996E-07	3.235E-07	3.323E-07	2.178E-07	4.169E-07	3.072E-07	2.578E-07	3.188E-07	2.811E-07	2.95019E-07
1-day	24	65725	2316.952797	2.342E-07	3.802E-07	3.852E-07	2.569E-07	4.821E-07	3.594E-07	3.08E-07	3.681E-07	3.29E-07	3.44774E-07
2-day	48	67050	2363.662002	2.644E-07	4.207E-07	3.908E-07	3.012E-07	5.132E-07	3.69E-07	3.551E-07	3.964E-07	3.294E-07	3.71141E-07
3-day	72	66950	2360.136779	2.781E-07	4.412E-07	4.111E-07	3.116E-07	5.324E-07	3.821E-07	3.739E-07	4.123E-07	3.43E-07	3.87299E-07
4-day	96	66755	2353.262594	2.831E-07	4.551E-07	4.181E-07	3.267E-07	5.561E-07	3.971E-07	3.851E-07	4.22E-07	3.481E-07	3.99044E-07
5-day	120	66725	2352.205027	2.913E-07	4.615E-07	4.264E-07	3.388E-07	5.671E-07	4.059E-07	3.954E-07	4.346E-07	3.649E-07	4.09543E-07
6-day	144	66635	2349.032326	3.013E-07	4.739E-07	4.378E-07	3.462E-07	5.822E-07	4.158E-07	4.05E-07	4.399E-07	3.684E-07	4.18938E-07
7-day	168	66570	2346.740931	2.986E-07	4.758E-07	4.368E-07	3.45E-07	5.825E-07	4.186E-07	4.052E-07	4.418E-07	3.673E-07	4.19077E-07
14-day	336	66260	2335.81274	3.324E-07	5.312E-07	4.881E-07	3.939E-07	6.497E-07	4.75E-07	4.57E-07	4.943E-07	4.136E-07	4.70571E-07
21-day	480	66030	2327.704727	3.395E-07	5.501E-07	4.965E-07	4.031E-07	6.7E-07	4.849E-07	4.639E-07	5.026E-07	4.201E-07	4.81189E-07
61-day	1464	67110	2365.777135	3.717E-07	6.228E-07	5.544E-07	4.544E-07	7.657E-07	5.436E-07	5.146E-07	5.658E-07	4.67E-07	5.39993E-07
2 month or 65 day	1560	67090	2365.072091	3.819E-07	6.32E-07	5.609E-07	4.599E-07	7.714E-07	5.482E-07	5.202E-07	5.712E-07	4.75E-07	5.46753E-07
3-month	2112	66885	2357.845384	3.963E-07	6.576E-07	5.875E-07	4.811E-07	8.049E-07	5.743E-07	5.413E-07	5.912E-07	4.867E-07	5.68994E-07
4-month	2712	66690	2350.971199	4.113E-07	6.814E-07	6.09E-07	5.008E-07	8.355E-07	5.969E-07	5.628E-07	6.15E-07	5.091E-07	5.91308E-07
5-month	3600	66550	2346.035887	4.197E-07	7.001E-07	6.212E-07	5.176E-07	8.617E-07	6.142E-07	5.808E-07	6.295E-07	5.206E-07	6.07271E-07
6-month	4344	66450	2342.510664	4.293E-07	7.15E-07	6.36E-07	5.274E-07	8.768E-07	6.29E-07	5.882E-07	6.394E-07	5.304E-07	6.19065E-07

Total Load Induced Strain vs. Time for 3-day Samples

Y-axis (per pound per square inch): 0, 0.0000001, 0.0000002, 0.0000003, 0.0000004, 0.0000005, 0.0000006, 0.0000007

X-axis — Time (hours): 0, 500, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000

Legend: Avg. Tot. Load Induced Strain

Creep Strain as defined in section 8 of A.S.T.M. C 512

												Temp (F)	Humidity (%)
3-hour	3	2.4664E-08	4.0802E-08	3.5008E-08	1.9878E-08	4.3331E-08	3.0937E-08	2.622E-08	2.341E-08	2.2951E-08	2.96891E-08	73.5	50%
1-day	24	5.918E-08	9.7521E-08	8.7851E-08	5.8948E-08	1.0851E-07	8.3136E-08	7.6376E-08	7.2677E-08	7.0798E-08	7.94441E-08	73.4	50%
2-day	48	8.9416E-08	1.3794E-07	9.3508E-08	1.0329E-07	1.3966E-07	9.2697E-08	1.2356E-07	1.0097E-07	1.1255E-07	1.05811E-07	73.9	51%
3-day	72	1.0315E-07	1.5846E-07	1.1375E-07	1.1368E-07	1.5886E-07	1.0586E-07	1.4227E-07	1.1683E-07	8.4844E-08	1.21968E-07	73.7	54%
4-day	96	1.0809E-07	1.7239E-07	1.2078E-07	1.287E-07	1.8256E-07	1.2084E-07	1.5356E-07	1.2653E-07	8.9968E-08	1.33714E-07	73.2	54%
5-day	120	1.1631E-07	1.7874E-07	1.2907E-07	1.4085E-07	1.9359E-07	1.2961E-07	1.6378E-07	1.3921E-07	1.0676E-07	1.44213E-07	73.8	52%
6-day	144	1.2631E-07	1.9115E-07	1.4048E-07	1.4822E-07	2.086E-07	1.3952E-07	1.7342E-07	1.4451E-07	1.1026E-07	1.53608E-07	73.6	53%
7-day	168	1.2368E-07	1.9308E-07	1.3944E-07	1.4709E-07	2.0892E-07	1.4237E-07	1.7357E-07	1.464E-07	1.0916E-07	1.53746E-07	73	53%
14-day	336	1.5738E-07	2.4845E-07	1.9074E-07	1.9599E-07	2.761E-07	1.9873E-07	2.2541E-07	1.9891E-07	1.5546E-07	2.05241E-07	73.9	52%
21-day	480	1.6457E-07	2.674E-07	1.9921E-07	2.0511E-07	2.9646E-07	2.0863E-07	2.3227E-07	2.0714E-07	1.6194E-07	2.15859E-07	73.4	51%
61-day	1464	1.9677E-07	3.4003E-07	2.5702E-07	2.5641E-07	3.9216E-07	2.6734E-07	2.8302E-07	2.7036E-07	2.0885E-07	2.74663E-07	73.7	50%
2 month or 65 day	1560	2.0693E-07	3.4929E-07	2.636E-07	2.6199E-07	3.9783E-07	2.7197E-07	2.8862E-07	2.7572E-07	2.1686E-07	2.81423E-07	73.8	50%
3-month	2112	2.213E-07	3.7486E-07	2.9019E-07	2.8315E-07	4.3137E-07	2.9804E-07	3.0971E-07	2.9575E-07	2.2859E-07	3.03664E-07	73	51%
4-month	2712	2.3631E-07	3.9868E-07	3.1162E-07	3.028E-07	4.6196E-07	3.2064E-07	3.1123E-07	3.1961E-07	2.5094E-07	3.25978E-07	73.6	50%
5-month	3600	2.447E-07	4.174E-07	3.2385E-07	3.1969E-07	4.8811E-07	3.3798E-07	3.4921E-07	3.3405E-07	2.6247E-07	3.41941E-07	73.6	50%
6-month	4344	2.5431E-07	4.3232E-07	3.3867E-07	3.2945E-07	5.0328E-07	3.5278E-07	3.5661E-07	3.4396E-07	2.7224E-07	3.53735E-07	73.4	51%

Creep Strain vs. Time for 3-day Samples

per pound-force per square inch

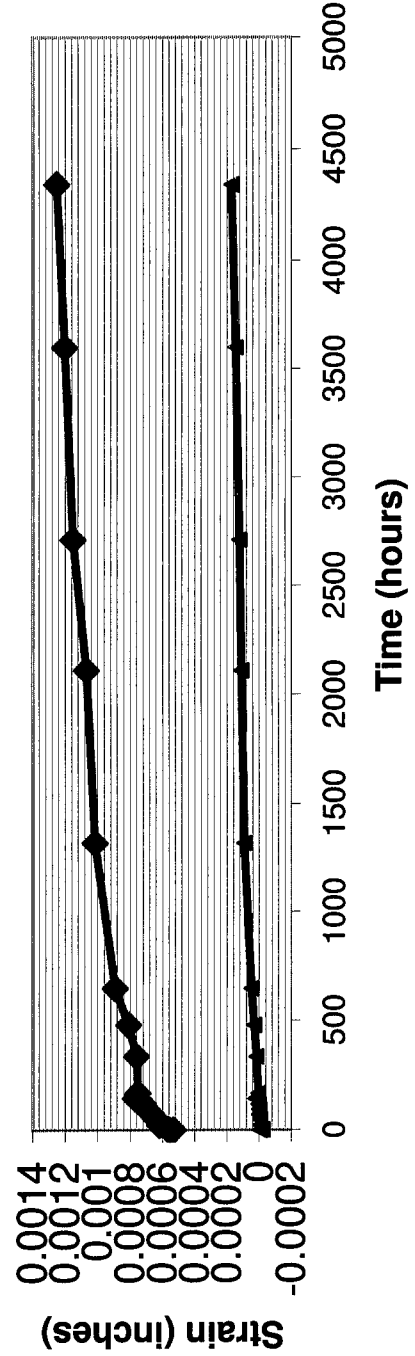Time (hours)

Avg. Creep

Section 2

30-Day Creep Data

Strain values for 30-day samples. Average strain consists of 90 readings. 9 sets of tabs read ten times.
The Average for the Control Samples consists of 90 readings. 9 sets of tabs read ten times.

All measurements read in inches

											Control Samples	Avg. Strain
after loading	1	0.000767261	0.000296092	0.000485653	0.00071249	0.00034489	0.000559512	0.00050056	0.000478282	0.000647312	-4.86848E-06	0.00053245
3-hour	3	0.000806813	0.000303545	0.00048049	0.000750336	0.000358652	0.000611706	0.000532114	0.000510951	0.000698362	-2.22011E-05	0.000561441
1-day	24	0.000891364	0.000337081	0.000542738	0.000830903	0.000357218	0.000689424	0.000594935	0.000559954	0.000769203	-6.74925E-06	0.000619202
2-day	48	0.000932636	0.000337654	0.000550197	0.000866456	0.000373846	0.000701469	0.000617309	0.000573137	0.000790999	-7.70463E-06	0.000638189
3-day	72	0.000961584	0.000356285	0.000576301	0.000901149	0.000397642	0.000722978	0.000636529	0.000599787	0.000817672	1.3136E-06	0.000663325
4-day	96	0.001005435	0.000385808	0.000593799	0.00094387	0.000408249	0.00078693	0.000678122	0.000627584	0.000859258	-1.14026E-06	0.000698784
5-day	120	0.001024925	0.000409312	0.000609863	0.000961646	0.000428891	0.000809873	0.000687302	0.000645352	0.000873598	2.10896E-06	0.000716751
6-day	144	0.00110403	0.000427083	0.000665514	0.001039059	0.000459281	0.000840272	0.000741804	0.000694641	0.000936121	2.20545E-05	0.000767534
7-day	168	0.00110489	0.000415331	0.000653179	0.001039919	0.000381014	0.000832528	0.000728896	0.000680026	0.000927804	4.81628E-06	0.00075151
14-day	336	0.001116354	0.000423357	0.000666949	0.001044507	0.000394201	0.000822778	0.000740943	0.000690343	0.000936408	1.59054E-05	0.000759538
21-day	480	0.00117511	0.000462053	0.000720591	0.001110165	0.000389901	0.000883289	0.000803191	0.000743358	0.000994629	3.11086E-05	0.000809143
28-day	648	0.001272558	0.000580145	0.000753867	0.001212236	0.000486803	0.000937204	0.00091908	0.000808696	0.001065756	4.85648E-05	0.000892927
2-month	1320	0.001437646	0.000682187	0.000873774	0.00137337	0.000614668	0.001046181	0.001031526	0.000896959	0.001183918	9.24693E-05	0.001015581
3-month	2112	0.001506433	0.000722316	0.000931146	0.001442182	0.000649071	0.001097802	0.001088897	0.000948541	0.001235542	0.00011025	0.001069103
4-month	2712	0.001549425	0.000845568	0.001002861	0.001490924	0.000801017	0.001135084	0.001246667	0.001054571	0.001249882	0.000122039	0.001152889
5-month	3600	0.001605028	0.000889709	0.001047038	0.001552281	0.000862369	0.001190719	0.001285105	0.001104434	0.001299786	0.000145809	0.001204052
6-month	4344	0.00166407	0.000943023	0.001100393	0.001611345	0.00090996	0.001232589	0.001321249	0.001146273	0.001341659	0.000171744	0.001252285

Average Strain of Loaded Samples and Shrinkage of Control Samples vs. Time for 30-day Samples

Strain (inches)
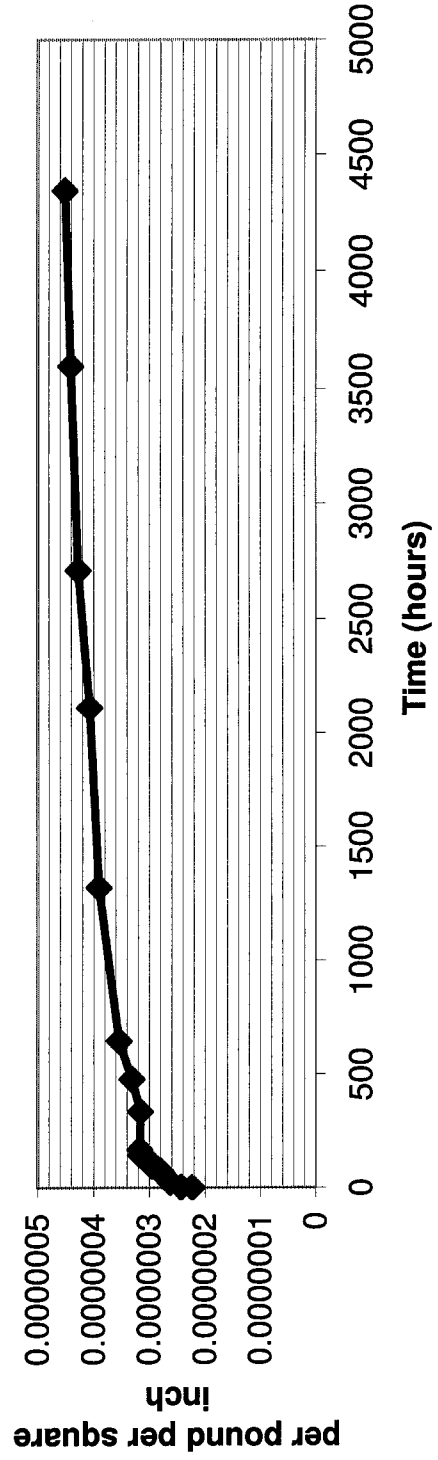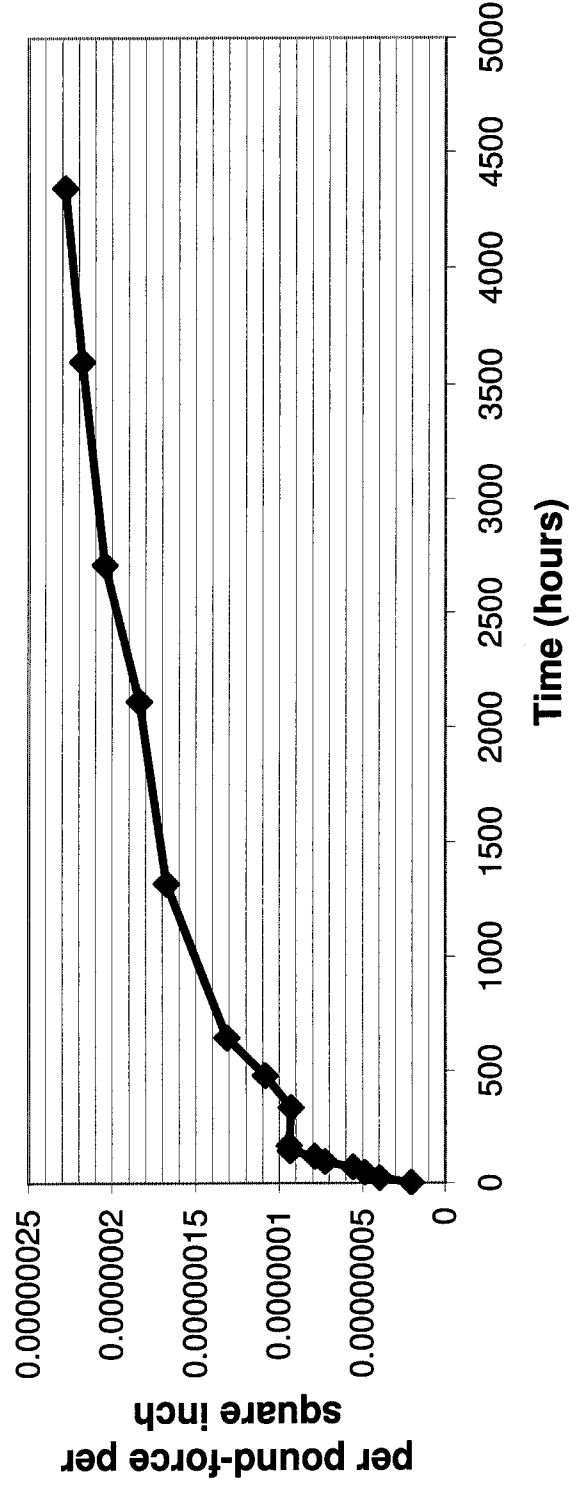
Time (hours)

Legend: Avg. Strain / Control Samples

Total Load-Induced Strain per pound per square inch   Measurements are defined as in section 8 of A.S.T.M. C 512 difference between the average strain values of the loaded and control specimens divided by the average stress.

Area of Cylinder   28.367 inches

Total Load-Induced Strain per pound per square inch

after loading	1	2408.079811	3.2064E-07	1.2498E-07	2.037E-07	2.979E-07	1.4524E-07	2.3437E-07	2.0989E-07	2.0064E-07	2.7083E-07	2.23132E-07
3-hour	3	2395.212747	3.4611E-07	1.36E-07	2.0987E-07	3.2253E-07	1.5901E-07	2.6466E-07	2.3143E-07	2.2259E-07	3.0083E-07	2.4367E-07
1-day	24	2383.226989	3.7685E-07	1.4427E-07	2.3056E-07	3.5148E-07	1.5272E-07	2.9211E-07	2.5247E-07	2.3779E-07	3.2559E-07	2.62649E-07
2-day	48	2376.881588	3.9562E-07	1.453E-07	2.3472E-07	3.6778E-07	1.6053E-07	2.9836E-07	2.6296E-07	2.4437E-07	3.3603E-07	2.7174E-07
3-day	72	2374.237671	4.0445E-07	1.4951E-07	2.4218E-07	3.79E-07	1.6693E-07	3.0396E-07	2.6754E-07	2.5207E-07	3.4384E-07	2.78831E-07
4-day	96	2367.716008	4.2513E-07	1.6343E-07	2.5127E-07	3.9912E-07	1.729E-07	3.3284E-07	2.8689E-07	2.6554E-07	3.6339E-07	2.95612E-07
5-day	120	2366.48218	4.3221E-07	1.7207E-07	2.5682E-07	4.0547E-07	1.8034E-07	3.4134E-07	2.8954E-07	2.7181E-07	3.6826E-07	3.01985E-07
6-day	144	2354.320161	4.5957E-07	1.7204E-07	2.7331E-07	4.3197E-07	1.8571E-07	3.4754E-07	3.0571E-07	2.8568E-07	3.8825E-07	3.16643E-07
7-day	168	2353.791377	4.6736E-07	1.7441E-07	2.7545E-07	4.3976E-07	1.5983E-07	3.5165E-07	3.0762E-07	2.8686E-07	3.9213E-07	3.1723E-07
14-day	336	2352.910072	4.677E-07	1.7317E-07	2.767E-07	4.3716E-07	1.6078E-07	3.4293E-07	3.0815E-07	2.8664E-07	3.9122E-07	3.16048E-07
21-day	480	2346.56467	4.8752E-07	1.8365E-07	2.9383E-07	4.5985E-07	1.529E-07	3.6316E-07	3.0353E-07	3.0353E-07	4.1061E-07	3.31563E-07
28-day	648	2381.111855	5.1404E-07	2.2325E-07	2.9621E-07	4.8871E-07	1.8405E-07	3.732E-07	3.6559E-07	3.1923E-07	4.2719E-07	3.54608E-07
2-month	1320	2362.956957	5.6928E-07	2.4957E-07	3.3065E-07	5.4208E-07	2.2099E-07	4.0361E-07	3.9741E-07	3.4046E-07	4.619E-07	3.9066E-07
3-month	2112	2355.906511	5.9263E-07	2.598E-07	3.4844E-07	5.6536E-07	2.2871E-07	4.1918E-07	4.154E-07	3.5583E-07	4.7765E-07	4.07E-07
4-month	2712	2410.371206	5.9219E-07	3.0017E-07	3.6543E-07	5.6791E-07	2.8169E-07	4.2029E-07	4.6658E-07	3.8688E-07	4.6791E-07	4.27672E-07
5-month	3600	2399.090492	6.0824E-07	3.1008E-07	3.7565E-07	5.8625E-07	2.9868E-07	4.3554E-07	4.7489E-07	3.9958E-07	4.8101E-07	4.41102E-07
6-month	4344	2393.802658	6.2341E-07	3.222E-07	3.8794E-07	6.0139E-07	3.0839E-07	4.4316E-07	4.802E-07	4.0711E-07	4.8873E-07	4.51391E-07

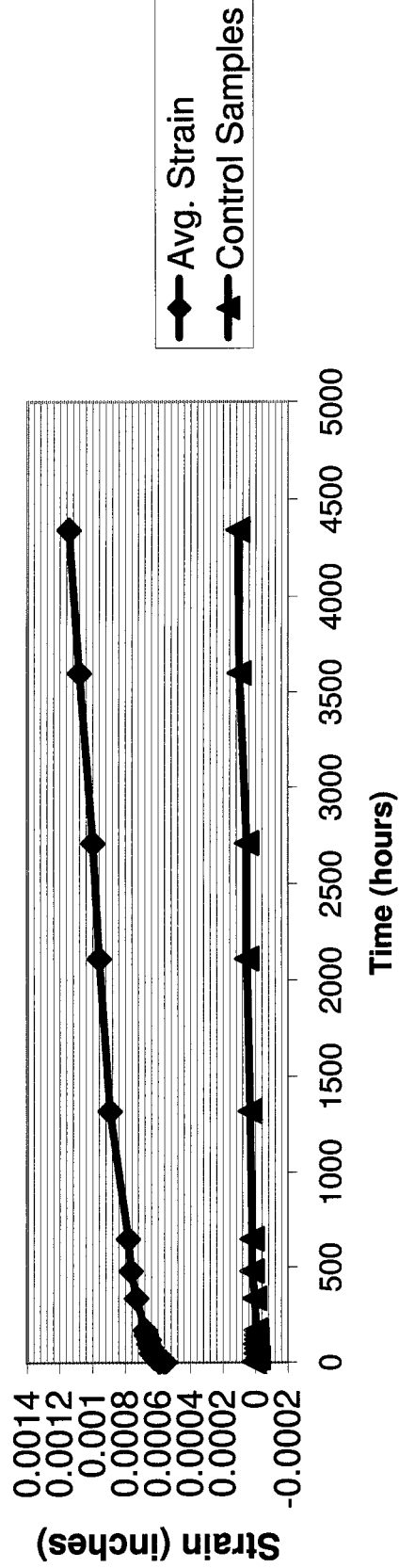## Total Load-Induced Strain vs. Time for 30-day Samples

Legend: ◆ Avg. Tot. Load Induced Strain

Y-axis: per pound per square inch — 0.0000005, 0.0000004, 0.0000003, 0.0000002, 0.0000001, 0

X-axis: Time (hours) — 0, 500, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000

Creep Strain as defined in section 8 of A.S.T.M. C 512

											Temp (F)	Humidity (%)
3-hour	3	2.5472E-08	1.10191E-08	6.17487E-09	2.46376E-08	1.37619E-08	3.02865E-08	2.15376E-08	2.19534E-08	3.00049E-08	2.05386E-08	73.4	52%
1-day	24	5.62064E-08	1.92912E-08	2.68662E-08	5.3582E-08	7.47652E-09	5.77443E-08	4.25776E-08	3.71509E-08	5.47587E-08	3.95171E-08	73.3	53%
2-day	48	7.49784E-08	2.03195E-08	3.10216E-08	6.988E-08	1.5282E-08	6.39936E-08	5.30669E-08	4.37337E-08	6.52003E-08	4.86084E-08	73	52%
3-day	72	8.38131E-08	2.45302E-08	3.84794E-08	8.11033E-08	2.16847E-08	6.95867E-08	5.76563E-08	5.14324E-08	7.30102E-08	5.56996E-08	73.1	50%
4-day	96	1.04484E-07	3.84474E-08	4.75732E-08	1.01227E-07	2.7661E-08	9.84704E-08	7.69966E-08	6.49032E-08	9.25576E-08	7.248E-08	73.3	53%
5-day	120	1.11568E-07	4.70916E-08	5.31194E-08	1.07573E-07	3.51007E-08	1.06966E-07	7.96521E-08	7.11765E-08	9.74337E-08	7.88535E-08	73.5	51%
6-day	144	1.38929E-07	4.7057E-08	6.96119E-08	1.34078E-07	4.04683E-08	1.13169E-07	9.58258E-08	8.50446E-08	1.17421E-07	9.35116E-08	76	50%
7-day	168	1.46721E-07	4.94265E-08	7.17564E-08	1.41864E-07	1.45822E-08	1.17281E-07	9.7734E-08	8.62233E-08	1.21298E-07	9.40985E-08	73.9	50%
14-day	336	1.47056E-07	4.81898E-08	7.29987E-08	1.39265E-07	1.5534E-08	1.08556E-07	9.82567E-08	8.60023E-08	1.20389E-07	9.29163E-08	73.6	51%
21-day	480	1.66881E-07	5.86694E-08	9.01281E-08	1.61949E-07	7.65725E-09	1.28791E-07	1.19138E-07	1.02891E-07	1.39779E-07	1.08432E-07	73.4	50%
28-day	648	1.93402E-07	9.82695E-08	9.25088E-08	1.90813E-07	3.88038E-08	1.38834E-07	1.55703E-07	1.18596E-07	1.56362E-07	1.31477E-07	73.5	52%
2-month	1320	2.48636E-07	1.24588E-07	1.26949E-07	2.44179E-07	7.57497E-08	1.6924E-07	1.87519E-07	1.39821E-07	1.9107E-07	1.67528E-07	73	51%
3-month	2112	2.7199E-07	1.34821E-07	1.44744E-07	2.67462E-07	8.34667E-08	1.84812E-07	2.05513E-07	1.55188E-07	2.06817E-07	1.83868E-07	73.5	52%
4-month	2712	2.71544E-07	1.75194E-07	1.61732E-07	2.70018E-07	1.36446E-07	1.85916E-07	2.5669E-07	1.86246E-07	1.97083E-07	2.04541E-07	73.6	50%
5-month	3600	2.87598E-07	1.85097E-07	1.71956E-07	2.88356E-07	1.53436E-07	2.01175E-07	2.64998E-07	1.98941E-07	2.10176E-07	2.1797E-07	73.3	51%
6-month	4344	3.02771E-07	1.97219E-07	1.84241E-07	3.0349E-07	1.63143E-07	2.08794E-07	2.70312E-07	2.17897E-07	2.17897E-07	2.28259E-07	73.9	50%

Creep Strain vs. Time for 30-day Samples

Legend: Avg. Creep

Y-axis: per pound-force per square inch

0.00000025
0.0000002
0.00000015
0.0000001
0.00000005
0

X-axis: Time (hours)

0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

Section 3

90-Day Creep Data

Strain values for 90-day samples. Average strain consists of 90 readings. 9 sets of tabs read ten times.

The Average for the Dummy Samples consists of 90 readings. 9 sets of tabs read ten times.

All measurements read in inches

										Control Samples	Avg. Strain
after loading	1	0.00039502	0.00070589	0.00069374	0.00064564	0.00057989	0.00036571	0.0005441	0.0005362	0.00054757	4.52276E-06	0.000557085
3-hour	3	0.00041366	0.00074587	0.00072556	0.00067861	0.00060369	0.00038663	0.00058854	0.00057373	0.00058627	8.56698E-06	0.000589173
1-day	24	0.00042369	0.00078931	0.00076484	0.00071903	0.0006361	0.0004001	0.00061979	0.00059693	0.00061981	-1.59854E-05	0.000618844
2-day	48	0.00044203	0.0008198	0.00078433	0.0007477	0.00065273	0.00041615	0.00064215	0.00061411	0.00063243	-3.50221E-06	0.000639049
3-day	72	0.0004363	0.0008221	0.00080153	0.0007477	0.00064585	0.00040813	0.00063584	0.00061583	0.00063472	-5.60411E-06	0.000638667
4-day	96	0.00045379	0.0008408	0.00082016	0.00076232	0.00066449	0.0004216	0.00066078	0.00062872	0.00065565	-3.34347E-06	0.000656479
5-day	120	0.00044576	0.00084367	0.00081386	0.00076633	0.0006622	0.00041988	0.00066078	0.00062299	0.00065278	-7.80132E-06	0.000654251
6-day	144	0.00044949	0.00086928	0.00083364	0.00078497	0.00067223	0.00043392	0.00067769	0.00064505	0.0006783	-6.17764E-06	0.000671619
7-day	168	0.00046325	0.00086237	0.00084969	0.00079644	0.00068772	0.00044424	0.00068285	0.00064276	0.00067658	-4.58566E-06	0.000678433
14-day	336	0.0004879	0.00093428	0.00089556	0.0008555	0.00073303	0.00047577	0.00074764	0.00070864	0.00075398	4.01207E-06	0.000732478
21-day	480	0.0005137	0.00098318	0.00093856	0.00089277	0.00075884	0.00050156	0.00077918	0.00074015	0.00078552	2.08904E-05	0.00076594
28-day	648	0.0005309	0.00101195	0.00095002	0.00090997	0.00078179	0.0005073	0.00080268	0.0007516	0.00079699	2.10175E-05	0.000782577
2-month	1320	0.00061977	0.00108386	0.00110769	0.00097591	0.00087643	0.0006592	0.00086231	0.00090341	0.0009604	3.52205E-05	0.000894331
3-month	2112	0.00067223	0.00116642	0.00118882	0.00104557	0.00094038	0.00071165	0.00090904	0.00097875	0.0010292	5.50287E-05	0.000960228
4-month	2712	0.00069717	0.0012133	0.00122523	0.00108772	0.00097107	0.00073658	0.00095691	0.00102658	0.00107507	5.5028E-05	0.000998848
5-month	3600	0.00076883	0.00130823	0.00132556	0.00116513	0.0010485	0.00081397	0.00103432	0.00110965	0.00116681	0.000100184	0.001082332
6-month	4344	0.00081756	0.00137439	0.0014087	0.00122533	0.00110873	0.00087415	0.00108305	0.00118125	0.00124422	0.000110057	0.001146375

Average Strain of Loaded Samples and Shrinkage of Control Samples vs. Time for 90-day Samples

Total Load-Induced Strain per pound per square inch   Measurements are defined as in section 8 of A.S.T.M. C 512 difference between the average strain values of the loaded and control specimens divided by the average stress.

Area of Cylinder   28.367 inches

Total Load-Induced Strain per pound per square inch

		Average Load	Average Stress										
after loading	1	68390	2410.899989	2.909E-07	1.62E-07	2.859E-07	2.659E-07	2.387E-07	1.498E-07	2.238E-07	2.205E-07	2.252E-07	2.29193E-07
3-hour	3	68180	2403.497021	3.068E-07	1.685E-07	2.983E-07	2.788E-07	2.476E-07	1.573E-07	2.413E-07	2.351E-07	2.404E-07	2.41567E-07
1-day	24	67815	2390.629957	3.369E-07	1.839E-07	3.266E-07	3.075E-07	2.728E-07	1.741E-07	2.659E-07	2.564E-07	2.66E-07	2.65549E-07
2-day	48	67900	2393.626397	3.44E-07	1.861E-07	3.291E-07	3.138E-07	2.742E-07	1.753E-07	2.697E-07	2.58E-07	2.657E-07	2.68442E-07
3-day	72	67620	2383.755773	3.472E-07	1.854E-07	3.386E-07	3.16E-07	2.733E-07	1.736E-07	2.691E-07	2.607E-07	2.686E-07	2.70276E-07
4-day	96	67650	2384.813339	3.54E-07	1.917E-07	3.453E-07	3.211E-07	2.8E-07	1.782E-07	2.785E-07	2.65E-07	2.763E-07	2.76677E-07
5-day	120	67510	2379.878027	3.578E-07	1.906E-07	3.453E-07	3.253E-07	2.815E-07	1.797E-07	2.809E-07	2.651E-07	2.776E-07	2.78188E-07
6-day	144	67420	2376.705327	3.683E-07	1.917E-07	3.534E-07	3.329E-07	2.854E-07	1.852E-07	2.877E-07	2.74E-07	2.88E-07	2.85183E-07
7-day	168	67385	2375.471499	3.65E-07	1.969E-07	3.596E-07	3.372E-07	2.914E-07	1.889E-07	2.894E-07	2.725E-07	2.867E-07	2.8753E-07
14-day	336	67095	2365.248352	3.933E-07	2.046E-07	3.769E-07	3.6E-07	3.082E-07	1.995E-07	3.144E-07	2.979E-07	3.171E-07	3.07987E-07
21-day	480	66970	2360.841823	4.076E-07	2.087E-07	3.887E-07	3.693E-07	3.126E-07	2.036E-07	3.212E-07	3.047E-07	3.239E-07	3.15586E-07
28-day	648	66810	2355.201466	4.207E-07	2.165E-07	3.944E-07	3.774E-07	3.23E-07	2.065E-07	3.319E-07	3.102E-07	3.295E-07	3.23352E-07
2-month	1320	68335	2408.961117	4.353E-07	2.427E-07	4.452E-07	3.905E-07	3.492E-07	2.59E-07	3.433E-07	3.604E-07	3.841E-07	3.56631E-07
3-month	2112	67990	2396.799098	4.637E-07	2.575E-07	4.73E-07	4.133E-07	3.694E-07	2.74E-07	3.563E-07	3.854E-07	4.064E-07	3.7767E-07
4-month	2712	67750	2388.338562	4.85E-07	2.689E-07	4.9E-07	4.324E-07	3.835E-07	2.854E-07	3.776E-07	4.068E-07	4.271E-07	3.95178E-07
5-month	3600	67675	2385.694645	5.064E-07	2.803E-07	5.136E-07	4.464E-07	3.975E-07	2.992E-07	3.916E-07	4.231E-07	4.471E-07	4.11682E-07
6-month	4344	67775	2389.219868	5.292E-07	2.961E-07	5.435E-07	4.668E-07	4.18E-07	3.198E-07	4.072E-07	4.483E-07	4.747E-07	4.33748E-07

Total Load-Induced Strain vs. Time for 90-day Samples

Y-axis (per pound per square inch): 0, 0.0000001, 0.0000002, 0.0000003, 0.0000004, 0.0000005

X-axis — Time (hours): 0, 500, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000

Legend: Avg. Tot. Load Induced Strain

Creep Strain as as defined in section 8 of A.S.T.M. C 512

												Temp (F)	Humidity (%)
3-hour	3	1.5849E-08	6.5688E-09	1.2437E-08	1.2854E-08	8.9561E-09	7.4838E-09	1.4608E-08	1.7494E-08	1.5114E-08	1.23738E-08	73.5	50%
1-day	24	4.5939E-08	2.1943E-08	4.0741E-08	4.1534E-08	3.4115E-08	2.4235E-08	3.5849E-08	4.2134E-08	4.0708E-08	3.63555E-08	73	50%
2-day	48	5.3041E-08	2.4162E-08	4.3261E-08	4.7911E-08	3.5508E-08	2.5508E-08	3.7493E-08	4.5927E-08	4.043E-08	3.9249E-08	73	51%
3-day	72	5.6312E-08	2.341E-08	5.2721E-08	5.0093E-08	3.4637E-08	2.3749E-08	4.0164E-08	4.528E-08	4.3374E-08	4.10822E-08	73	50%
4-day	96	6.305E-08	2.9712E-08	5.9437E-08	5.5136E-08	4.1385E-08	2.8372E-08	4.4506E-08	5.4671E-08	5.1083E-08	4.74834E-08	73.6	53%
5-day	120	6.6866E-08	2.861E-08	5.9376E-08	5.9361E-08	4.2874E-08	2.9892E-08	4.4521E-08	5.7122E-08	5.2324E-08	4.89941E-08	73	50%
6-day	144	7.7432E-08	2.9749E-08	6.7476E-08	6.6953E-08	4.679E-08	3.5358E-08	5.3472E-08	6.393E-08	6.2747E-08	5.59897E-08	73.5	51%
7-day	168	7.4047E-08	3.4971E-08	7.3747E-08	7.1283E-08	5.2788E-08	3.9128E-08	5.1979E-08	6.5582E-08	6.1502E-08	5.83363E-08	73.5	51%
14-day	336	1.0239E-07	4.261E-08	9.1059E-08	9.4075E-08	6.957E-08	4.9638E-08	7.7375E-08	9.0589E-08	9.1833E-08	7.87937E-08	73	49%
21-day	480	1.1669E-07	4.6771E-08	1.0283E-07	1.0338E-07	7.3929E-08	5.3788E-08	8.4128E-08	9.7384E-08	9.8633E-08	8.63928E-08	74	51%
28-day	648	1.2983E-07	5.452E-08	1.0857E-07	1.1152E-07	8.4365E-08	5.6655E-08	8.9668E-08	1.0808E-07	1.0422E-07	9.41589E-08	73.5	50%
2-month	1320	1.4439E-07	8.0682E-08	1.5932E-07	1.2457E-07	1.1055E-07	1.0921E-07	1.3987E-07	1.1953E-07	1.5881E-07	1.27437E-07	73.6	51%
3-month	2112	1.7278E-07	9.5536E-08	1.8717E-07	1.4736E-07	1.3074E-07	1.2414E-07	1.6486E-07	1.325E-07	1.812E-07	1.48477E-07	73.5	50%
4-month	2712	1.9406E-07	1.0689E-07	2.0409E-07	1.6647E-07	1.449E-07	1.3555E-07	1.8626E-07	1.5381E-07	2.0185E-07	1.65985E-07	73.5	51%
5-month	3600	2.1545E-07	1.183E-07	2.2776E-07	1.8046E-07	1.5885E-07	1.4938E-07	2.026E-07	1.6775E-07	2.2185E-07	1.82488E-07	73.3	51%
6-month	4344	2.3827E-07	1.3415E-07	2.5767E-07	2.0087E-07	1.7934E-07	1.7E-07	2.2781E-07	1.8343E-07	2.4945E-07	2.04554E-07	73	50%

Creep Strain vs. Time for 90-day Samples

Legend: ◆ Avg. Creep

Y-axis (per pound-force per square inch): 0, 0.00000005, 0.0000001, 0.00000015, 0.0000002, 0.00000025

X-axis (Time (hours)): 0, 500, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000

Section 4

Modulus of Elasticity

Static Modulus of Elasticity for 3 Day Creep Samples

DATE | May 27, 1999

Compressive Strength for 3 day breaks

	A	B	C	Avg.
Max Load	166700	173400	176000	172033.3333
X-Sect(A)	28.2744	28.2744	28.2744	
Comp Str.	5895.79266	6132.756133	6224.712107	6084.4203

Static Modulus of Elasticity
40% of   172033.3333   =   ███████   lbs.

Load Rate 60000 lbs per minute
Vertical Gage Length = 16 inches
Horizontal Gage Length = 12 inches

Sample 3-A

Load	Vert. 1	Vert. 2	Avg. Vert.	Long. Strain	Stress(psi)	Horizont. 1	Horizont. 2	Avg.Horizont	Transverse Strain
0	0	0	0	0	0	0	0		
0	0	0	0	0	0	0	0	0	0
8600	0.0008	0.0008	0.0008	0.00005	304.1620689	0	0	0	0
8000	0.0008	0.0008	0.0008	0.00005	282.9414594	0	0		0
10000	0.001	0.001	0.001	0.0000625	353.6768243	0	0	0	0
15000	0.0015	0.0015	0.0015	0.00009375	530.5152364	0.0001	0	0.00005	4.16667E-06
20000	0.0021	0.002	0.00205	0.000128125	707.3536485	0.0002	0.00015	0.000175	1.45833E-05
25000	0.0028	0.0027	0.00275	0.000171875	884.1920607	0.0003	0.0002	0.00025	2.08333E-05
30000	0.0033	0.0033	0.0033	0.00020625	1061.030473	0.0004	0.0003	0.00035	2.91667E-05
35000	0.00395	0.0039	0.003925	0.000245313	1237.868885	0.0005	0.0004	0.00045	0.0000375
40000	0.0046	0.0045	0.00455	0.000284375	1414.707297	0.0006	0.0005	0.00055	4.58333E-05
45000	0.005	0.0051	0.00505	0.000315625	1591.545709	0.0008	0.0006	0.0007	5.83333E-05
50000	0.0057	0.0057	0.0057	0.00035625	1768.384121	0.0009	0.0007	0.0008	6.66667E-05
55000	0.0064	0.0064	0.0064	0.0004	1945.222533	0.001	0.0008	0.0009	0.000075
60000	0.007	0.007	0.007	0.0004375	2122.060946	0.0011	0.00095	0.001025	8.54167E-05
65000	0.0077	0.0077	0.0077	0.00048125	2298.899358	0.0012	0.00105	0.001125	0.00009375
68800	0.0082	0.0082	0.0082	0.0005125	2433.296551	0.0013	0.0011		0.000108333
68800	0.008	0.008	0.008	0.0005	2433.296551	0.0011	0.0011	0.0011	9.16667E-05

$S2$ = stress at 40% of ult. Load
$e2$ = Longitudinal strain @ $S2$
$S1$ = stress @ strain of 50 uin/in
E = Young's Modulus of Elasticity
u = Poisson's ratio
$et2$ = transverse strain at mid-height of the specimen
   produced by stress $S2$
$et1$ = transverse strain at mid-height of the specimen
   produced by stress $S1$
Longitudinal Strain at .000050 - .000050 * 16 = .0008
$E = ((S2-S1)/((e2-0.000050))*A)$
$u = (et2-et1)/(e2-0.000050)$

Run 1

E =   4649416.414 psi
u =   0.234234234

Run 2

E =   4731409.96 psi
u =   0.203703704

Sample 3-C

Load	Vert. 1	Vert. 2	Avg. Vert.	Long. Strain	Stress(psi)	Horizont. 1	Horizont. 2	Avg.Horizont	Transverse Strain
0	0	0	0	0	0	0	0		0
	0	0	0	0	0	0	0		
8600		0.0008	0	0.00005	304.1620689		0.0001		8.33333E-06
8000	0.0008	0.0008		0.00005	282.9414594	0.0001	0.0001		8.33333E-06
10000	0.001	0.001	0.001	0.0000625	353.6768243	0.0002	0.0002	0.00015	0.0000125
15000	0.0016	0.0016	0.0016	0.0001	530.5152364	0.0003	0.00035	0.00025	2.08333E-05
20000	0.0022	0.0021	0.00215	0.000134375	707.3536485	0.00035	0.00045	0.00035	2.91667E-05
25000	0.0029	0.0029	0.0029	0.00018125	884.1920607	0.00045	0.00055	0.00045	0.0000375
30000	0.0036	0.0036	0.0036	0.000225	1061.030473	0.00055	0.00065	0.00055	4.58333E-05
35000	0.0043	0.0044	0.00435	0.000271875	1237.868885	0.00065	0.0008	0.00065	5.41667E-05
40000	0.005	0.005	0.005	0.0003125	1414.707297	0.0008	0.0009	0.0008	6.66667E-05
45000	0.0057	0.0059	0.0058	0.0003625	1591.545709	0.0009	0.001	0.0009	0.000075
50000	0.0065	0.0066	0.00655	0.000409375	1768.384121	0.001	0.00105	0.001	8.33333E-05
55000	0.0071	0.0073	0.0072	0.00045	1945.222533	0.0011	0.00115	0.001075	8.95833E-05
60000	0.0079	0.0079	0.0079	0.00049375	2122.060946	0.0012	0.0013	0.001175	9.79167E-05
65000	0.0085	0.0086	0.00855	0.000534375	2298.899358	0.00135		0.001325	0.000110417
68800	0.009			0.0005625	2433.296551	0.00145			0.000120833
68800		0.0091		0.00056875	2433.296551		0.0014		0.000116667

S2 = stress at 40% of ult. Load
e2 = Longitudinal strain @ S2
S1 = stress @ strain of 50 uin/in
E = Young's Modulus of Elasticity
u = Poisson's ratio
e_{t2} = transverse strain at mid-height of the specimen
    produced by stress S2
e_{t1} = transverse strain at mid-height of the specimen
    produced by stress S1
Longitudinal Strain at .000050 - .000050 * 16 = .0008
E = ((S2-S1)/((e2-0.000050))*A)
u = (et2-et1)/(e2-0.000050)

Run 1

E = 4195814.813   psi
u = 0.219512195

Run 2

E = 4104355.628   psi
u = 0.208835341

		E		**u**
3A	run 1	4649416.414	psi	0.234234234
	run 2	4731409.96	psi	0.203703704
3C	run1	4195814.813	psi	0.219512195
	run2	4104355.628	psi	0.208835341
Standard Deviation		315963.1696		0.013491333
Average		4420249.204		
Coefficient of Variation		7.148084984		

Section 5

Cylinder Height, Diameter, and Weight

unit weight of concrete for Owensboro Bridge

Date

cylinder	weight(lbs)	height(in)	diameter(in)	area(in^2)	volume(ft^3)	unit weight (lbs/cf)
1	28.3	11.977	5.9935	28.21310601	0.195548826	144.7208896
2	29.1	11.965	6.006	28.33091082	0.196168604	148.3417804
3	29.2	12.0195	5.99	28.18016464	0.196013593	148.9692604
4	29	11.981	6.014	28.40643471	0.196954568	147.2420784
5	28.7	12.022	6.006	28.33091082	0.197103131	145.6090519
6	29.2	12.001	5.997	28.24606662	0.196169586	148.8508006
7	29	11.995	5.993	28.20839892	0.195810038	148.1027242
8	28.7	11.9915	5.9935	28.21310601	0.195785568	146.5889461
9	28.8	12.011	5.9995	28.26962169	0.196496774	146.5672915
10	28.4	12.0025	5.997	28.24606662	0.196194106	144.7546036

average (Diam.)	5.99895	inches
average (area)	28.26443873	inches^2

| average unit weight | 146.9747427 | lbs/cf |

Section 6

ASTM C-39
ASTM C-469
ASTM C-512

Standard Test Method for
Compressive Strength of Cylindrical Concrete Specimens[1]

This standard is issued under the fixed designation C 39; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This test method has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This test method covers determination of compressive strength of cylindrical concrete specimens such as molded cylinders and drilled cores. It is limited to concrete having a unit weight in excess of 50 lb/ft³ (800 kg/m³).

1.2 The values stated in inch-pound units are to be regarded as the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.4 The text of this standard references notes which provide explanatory material. These notes shall not be considered as requirements of the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

C 31 Practice for Making and Curing Concrete Test Specimens in the Field[2]

C 42 Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete[2]

C 192 Practice for Making and Curing Concrete Test Specimens in the Laboratory[2]

C 617 Practice for Capping Cylindrical Concrete Specimens[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

C 873 Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds[2]

C 1077 Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation[2]

C 1231 Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders[2]

E 4 Practices for Force Verification of Testing Machines[3]

E 74 Practice for Calibration of Force-Measuring Instruments for Verifying the Load Indication of Testing Machines[3]

Manual of Aggregate and Concrete Testing[2]

2.2 *American Concrete Institute:*

CP-16 Concrete Laboratory Testing Technician, Grade I.[4]

3. Summary of Test Method

3.1 This test method consists of applying a compressive axial load to molded cylinders or cores at a rate which is within a prescribed range until failure occurs. The compressive strength of the specimen is calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen.

4. Significance and Use

4.1 Care must be exercised in the interpretation of the significance of compressive strength determinations by this test method since strength is not a fundamental or intrinsic property of concrete made from given materials. Values obtained will depend on the size and shape of the specimen, batching, mixing procedures, the methods of sampling, molding, and fabrication and the age, temperature, and moisture conditions during curing.

4.2 This test method is used to determine compressive strength of cylindrical specimens prepared and cured in accordance with Practices C 31, C 192, C 617 and C 1231 and Test Methods C 42 and C 873.

4.3 The results of this test method are used as a basis for quality control of concrete proportioning, mixing, and placing operations; determination of compliance with specifications; control for evaluating effectiveness of admixtures and similar uses.

4.4 The individual who tests concrete cylinders for acceptance testing shall have demonstrated a knowledge and ability to perform the test procedure equivalent to the minimum guidelines for certification of Concrete Laboratory Technician, Level I, in accordance with ACI CP-16.

NOTE 1—The testing laboratory performing this test method should be evaluated in accordance with Practice C 1077.

5. Apparatus

5.1 *Testing Machine*—The testing machine shall be of a type having sufficient capacity and capable of providing the rates of loading prescribed in 7.5.

5.1.1 Verification of calibration of the testing machines in accordance with Practices E 4 is required under the following conditions:

5.1.1.1 After an elapsed interval since the previous verifi-

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cation of 18 months maximum, but preferably after an interval of 12 months,

5.1.1.2 On original installation or relocation of the machine,

5.1.1.3 Immediately after making repairs or adjustments that affect the operation of the force applying system of the machine or the values displayed on the load indicating system, except for zero adjustments that compensate for the mass of bearing blocks, or specimen, or both, or

5.1.1.4 Whenever there is reason to doubt the accuracy of the results, without regard to the time interval since the last verification.

5.1.2 *Design*—The design of the machine must include the following features:

5.1.2.1 The machine must be power operated and must apply the load continuously rather than intermittently, and without shock. If it has only one loading rate (meeting the requirements of 7.5), it must be provided with a supplemental means for loading at a rate suitable for verification. This supplemental means of loading may be power or hand operated.

NOTE 2—High-strength concrete cylinders rupture more intensely than normal strength cylinders. As a safety precaution, it is recommended that the testing machines should be equipped with protective fragment guards.

5.1.2.2 The space provided for test specimens shall be large enough to accommodate, in a readable position, an elastic calibration device which is of sufficient capacity to cover the potential loading range of the testing machine and which complies with the requirements of Practice E 74.

NOTE 3—The types of elastic calibration devices most generally available and most commonly used for this purpose are the circular proving ring or load cell.

5.1.3 *Accuracy*—The accuracy of the testing machine shall be in accordance with the following provisions:

5.1.3.1 The percentage of error for the loads within the proposed range of use of the testing machine shall not exceed ±1.0 % of the indicated load.

5.1.3.2 The accuracy of the testing machine shall be verified by applying five test loads in four approximately equal increments in ascending order. The difference between any two successive test loads shall not exceed one third of the difference between the maximum and minimum test loads.

5.1.3.3 The test load as indicated by the testing machine and the applied load computed from the readings of the verification device shall be recorded at each test point. Calculate the error, E, and the percentage of error, E_p, for each point from these data as follows:

$$E = A - B$$
$$E_p = 100(A - B)/B$$

where:

A = load, lbf (or N) indicated by the machine being verified, and

B = applied load, lbf (or N) as determined by the calibrating device.

5.1.3.4 The report on the verification of a testing machine shall state within what loading range it was found to conform to specification requirements rather than reporting a blanket acceptance or rejection. In no case shall the loading range be stated as including loads below the value which is 100 times the smallest change of load estimable on the load-indicating mechanism of the testing machine or loads within that portion of the range below 10 % of the maximum range capacity.

5.1.3.5 In no case shall the loading range be stated as including loads outside the range of loads applied during the verification test.

5.1.3.6 The indicated load of a testing machine shall not be corrected either by calculation or by the use of a calibration diagram to obtain values within the required permissible variation.

5.2 The testing machine shall be equipped with two steel bearing blocks with hardened faces (Note 4), one of which is a spherically seated block that will bear on the upper surface of the specimen, and the other a solid block on which the specimen shall rest. Bearing faces of the blocks shall have a minimum dimension at least 3 % greater than the diameter of the specimen to be tested. Except for the concentric circles described below, the bearing faces shall not depart from a plane by more than 0.001 in. (0.025 mm) in any 6 in. (152 mm) of blocks 6 in. in diameter or larger, or by more than 0.001 in. in the diameter of any smaller block; and new blocks shall be manufactured within one half of this tolerance. When the diameter of the bearing face of the spherically seated block exceeds the diameter of the specimen by more than ½ in. (13 mm), concentric circles not more than 1/32 in. (0.8 mm) deep and not more than 3/64 in. (1.2 mm) wide shall be inscribed to facilitate proper centering.

NOTE 4—It is desirable that the bearing faces of blocks used for compression testing of concrete have a Rockwell hardness of not less than 55 HRC.

5.2.1 Bottom bearing blocks shall conform to the following requirements:

5.2.1.1 The bottom bearing block is specified for the purpose of providing a readily machinable surface for maintenance of the specified surface conditions (Note 5). The top and bottom surfaces shall be parallel to each other. If the testing machine is so designed that the platen itself is readily maintained in the specified surface condition, a bottom block is not required. Its least horizontal dimension shall be at least 3 % greater than the diameter of the specimen to be tested. Concentric circles as described in 5.2 are optional on the bottom block.

NOTE 5—The block may be fastened to the platen of the testing machine.

5.2.1.2 Final centering must be made with reference to the upper spherical block. When the lower bearing block is used to assist in centering the specimen, the center of the concentric rings, when provided, or the center of the block itself must be directly below the center of the spherical head. Provision shall be made on the platen of the machine to assure such a position.

5.2.1.3 The bottom bearing block shall be at least 1 in. (25 mm) thick when new, and at least 0.9 in. (22.5 mm) thick after any resurfacing operations.

5.2.2 The spherically seated bearing block shall conform to the following requirements:

5.2.2.1 The maximum diameter of the bearing face of the

suspended spherically seated block shall not exceed the values given below:

Diameter of Test Specimens, in. (mm)	Maximum Diameter of Bearing Face, in. (mm)
2 (51)	4 (102)
3 (76)	5 (127)
4 (102)	6½ (165)
6 (152)	10 (254)
8 (203)	11 (279)

Note 6—Square bearing faces are permissible, provided the diameter of the largest possible inscribed circle does not exceed the above diameter.

5.2.2.2 The center of the sphere shall coincide with the surface of the bearing face within a tolerance of ±5 % of the radius of the sphere. The diameter of the sphere shall be at least 75 % of the diameter of the specimen to be tested.

5.2.2.3 The ball and the socket must be so designed by the manufacturer that the steel in the contact area does not permanently deform under repeated use, with loads up to 12 000 psi (82.7 MPa) on the test specimen.

Note 7—The preferred contact area is in the form of a ring (described as preferred "bearing" area) as shown on Fig. 1.

5.2.2.4 The curved surfaces of the socket and of the spherical portion shall be kept clean and shall be lubricated with a petroleum-type oil such as conventional motor oil, not with a pressure type grease. After contacting the specimen and application of small initial load, further tilting of the spherically seated block is not intended and is undesirable.

5.2.2.5 If the radius of the sphere is smaller than the radius of the largest specimen to be tested, the portion of the bearing face extending beyond the sphere shall have a thickness not less than the difference between the radius of the sphere and radius of the specimen. The least dimension of the bearing face shall be at least as great as the diameter of the sphere (see Fig. 1).

5.2.2.6 The movable portion of the bearing block shall be held closely in the spherical seat, but the design shall be such that the bearing face can be rotated freely and tilted at least 4° in any direction.

5.3 *Load Indication:*

5.3.1 If the load of a compression machine used in concrete testing is registered on a dial, the dial shall be provided with a graduated scale that is readable to at least the nearest 0.1 % of the full scale load (Note 8). The dial shall be readable within 1 % of the indicated load at any given load level within the loading range. In no case shall the loading range of a dial be considered to include loads below the value that is 100 times the smallest change of load that can be read on the scale. The scale shall be provided with a graduation line equal to zero and so numbered. The dial pointer shall be of sufficient length to reach the graduation marks; the width of the end of the pointer shall not exceed the clear distance between the smallest graduations. Each dial shall be equipped with a zero adjustment located outside the dialcase and easily accessible from the front of the machine while observing the zero mark and dial pointer. Each dial shall be equipped with a suitable device that at all times until reset, will indicate to within 1 % accuracy the maximum load applied to the specimen.

Note 8—Readability is considered to be $\frac{1}{50}$ in. (0.5 mm) along the arc described by the end of the pointer. Also, one half of a scale interval is readable with reasonable certainty when the spacing on the load indicating mechanism is between $\frac{1}{25}$ in. (1 mm) and $\frac{1}{16}$ in. (1.6 mm). When the spacing is between $\frac{1}{16}$ in. and $\frac{1}{8}$ in. (3.2 mm), one third of a scale interval is readable with reasonable certainty. When the spacing is $\frac{1}{8}$ in. or more, one fourth of a scale interval is readable with reasonable certainty.

5.3.2 If the testing machine load is indicated in digital form, the numerical display must be large enough to be easily read. The numerical increment must be equal to or less than 0.10 % of the full scale load of a given loading range. In no case shall the verified loading range include loads less than the minimum numerical increment multiplied by 100. The accuracy of the indicated load must be within 1.0 % for any value displayed within the verified loading range. Provision must be made for adjusting to indicate true zero at zero load. There shall be provided a maximum load indicator that at all times until reset will indicate within 1 % system accuracy the maximum load applied to the specimen.

6. Specimens

6.1 Specimens shall not be tested if any individual diameter of a cylinder differs from any other diameter of the same cylinder by more than 2 %.

Note 9—This may occur when single use molds are damaged or deformed during shipment, when flexible single use molds are deformed during molding or when a core drill deflects or shifts during drilling.

6.2 Neither end of compressive test specimens when tested shall depart from perpendicularity to the axis by more than 0.5° (approximately equivalent to $\frac{1}{8}$ in. in 12 in. (3 mm in 300 mm)). The ends of compression test specimens that are not plane within 0.002 in. (0.050 mm) shall be sawed or ground to meet that tolerance, or capped in accordance with either Practice C 617 or Practice C 1231. The diameter used for calculating the cross-sectional area of the test specimen shall be determined to the nearest 0.01 in. (0.25 mm) by averaging two diameters measured at right angles to each other at about midheight of the specimen.

SOCKET

PREFERRED BEARING AREA

BALL

R

T MUST BE NO LESS THAN (R−r)

TEST SPECIMEN
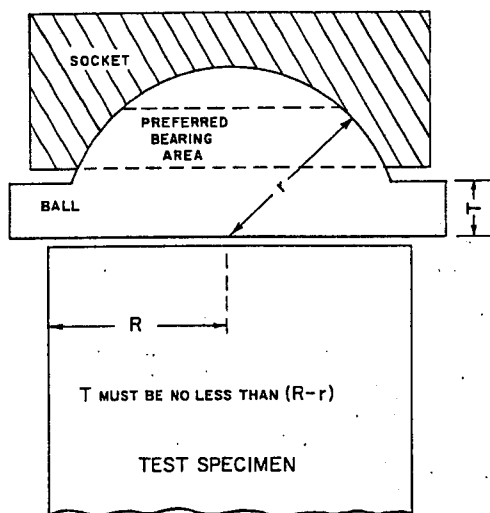
Note—Provision shall be made for holding the ball in the socket and for holding the entire unit in the testing machine.

FIG. 1 Schematic Sketch of a Typical Spherical Bearing Block

6.3 The number of individual cylinders measured for determination of average diameter may be reduced to one for each ten specimens or three specimens per day, whichever is greater, if all cylinders are known to have been made from a single lot of reusable or single-use molds which consistently produce specimens with average diameters within a range of 0.02 in. (0.51 mm). When the average diameters do not fall within the range of 0.02 in. or when the cylinders are not made from a single lot of molds, each cylinder tested must be measured and the value used in calculation of the unit compressive strength of that specimen. When the diameters are measured at the reduced frequency, the cross-sectional areas of all cylinders tested on that day shall be computed from the average of the diameters of the three or more cylinders representing the group tested that day.

6.4 The length shall be measured to the nearest 0.05 D when the length to diameter ratio is less than 1.8, or more than 2.2, or when the volume of the cylinder is determined from measured dimensions.

7. Procedure

7.1 Compression tests of moist-cured specimens shall be made as soon as practicable after removal from moist storage.

7.2 Test specimens shall be kept moist by any convenient method during the period between removal from moist storage and testing. They shall be tested in the moist condition.

7.3 All test specimens for a given test age shall be broken within the permissible time tolerances prescribed as follows:

Test Age	Permissible Tolerance
24 h	± 0.5 h or 2.1 %
3 days	2 h or 2.8 %
7 days	6 h or 3.6 %
28 days	20 h or 3.0 %
90 days	2 days 2.2 %

7.4 *Placing the Specimen*—Place the plain (lower) bearing block, with its hardened face up, on the table or platen of the testing machine directly under the spherically seated (upper) bearing block. Wipe clean the bearing faces of the upper and lower bearing blocks and of the test specimen and place the test specimen on the lower bearing block. Carefully align the axis of the specimen with the center of thrust of the spherically seated block.

7.4.1 *Zero Verification and Block Seating*—Prior to testing the specimen, verify that the load indicator is set to zero. In cases where the indicator is not properly set to zero, adjust the indicator (Note 10). As the spherically seated block is brought to bear on the specimen, rotate its movable portion gently by hand so that uniform seating is obtained.

NOTE 10—The technique used to verify and adjust load indicator to zero will vary depending on the machine manufacturer. Consult your owner's manual or compression machine calibrator for the proper technique.

7.5 *Rate of Loading*—Apply the load continuously and without shock.

7.5.1 For testing machines of the screw type, the moving head shall travel at a rate of approximately 0.05 in. (1.3 mm)/min when the machine is running idle. For hydraulically operated machines, the load shall be applied at a rate of movement (platen to crosshead measurement) corresponding to a loading rate on the specimen within the range of 20 to 50 psi/s (0.14 to 0.34 MPa/s). The designated rate of movement shall be maintained at least during the latter half of the anticipated loading phase of the testing cycle.

7.5.2 During the application of the first half of the anticipated loading phase a higher rate of loading shall be permitted.

7.5.3 Make no adjustment in the rate of movement of the platen at any time while a specimen is yielding rapidly immediately before failure.

7.6 Apply the load until the specimen fails, and record the maximum load carried by the specimen during the test. Note the type of failure and the appearance of the concrete.

8. Calculation

8.1 Calculate the compressive strength of the specimen by dividing the maximum load carried by the specimen during the test by the average cross-sectional area determined as described in Section 6 and express the result to the nearest 10 psi (69 kPa).

8.2 If the specimen length to diameter ratio is less than 1.8, correct the result obtained in 8.1 by multiplying by the appropriate correction factor shown in the following table:

L/D:	1.75	1.50	1.25	1.00
Factor:	0.98	0.96	0.93	0.87 (Note 11)

NOTE 11—These correction factors apply to lightweight concrete weighing between 100 and 120 lb/ft³ (1600 and 1920 kg/m³) and to normal weight concrete. They are applicable to concrete dry or soaked at the time of loading. Values not given in the table shall be determined by interpolation. The correction factors are applicable for nominal concrete strengths from 2000 to 6000 psi (13.8 to 41.4 MPa).

9. Report

9.1 Report the following information:

9.1.1 Identification number,

9.1.2 Diameter (and length, if outside the range of 1.8D to 2.2D), in inches or millimetres,

9.1.3 Cross-sectional area, in square inches or square centimetres,

9.1.4 Maximum load, in pounds-force or newtons,

9.1.5 Compressive strength calculated to the nearest 10 psi or 69 kPa,

9.1.6 Type of fracture, if other than the usual cone (see Fig. 2),

9.1.7 Defects in either specimen or caps, and,

9.1.8 Age of specimen.

10. Precision and Bias

10.1 *Precision*—The single operator precision of tests of individual 6 by 12 in. (150 by 300 mm) cylinders made from a well-mixed sample of concrete is given for cylinders made in a laboratory environment and under normal field conditions (see 10.1.1).

Cone	Cone and Split	Cone and Shear	Shear	Columnar
(a)	(b)	(c)	(d)	(e)
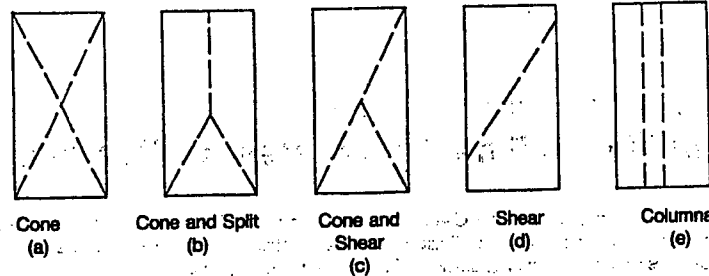
FIG. 2 Sketches of Types of Fracture

| | Coefficient of Variation[A] | Acceptable Range of[A] | |
		2 results	3 results
Single operator			
Laboratory conditions	2.37 %	6.6 %	7.8 %
Field conditions	2.87 %	8.0 %	9.5 %

[A] These numbers represent respectively the (1s) and (d2s) limits as described in Practice C 670.

10.1.1 The values given are applicable to 6 by 12 in. (150 by 300 mm) cylinders with compressive strength between 2000 and 8000 psi (12 to 55 MPa). They are derived from CCRL concrete reference sample data for laboratory conditions and a collection of 1265 test reports from 225 commercial testing laboratories in 1978.[5]

NOTE 12—Subcommittee C09.03.01 will re-examine recent CCRL Concrete Reference Sample Program data and field test data to see if these values are representative of current practice and if they can be extended to cover a wider range of strengths and specimen sizes.

10.2 *Bias*—Since there is no accepted reference material, no statement on bias is being made.

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[5] Research report RR:C09-1006 is on file at ASTM Headquarters.

Standard Test Method for
Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression[1]

Scope

1.1 This test method covers determination of (1) chord modulus of elasticity (Young's) and (2) Poisson's ratio of molded concrete cylinders and diamond-drilled concrete cores when under longitudinal compressive stress. Chord modulus of elasticity and Poisson's ratio are defined in Terminology E 6.

1.2 The values stated in inch-pound units are to be regarded as the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Referenced Documents

2.1 *ASTM Standards:*

Practice for Making and Curing Concrete Test Specimens in the Field[2]

C 39 Test Method for Compressive Strength of Cylindrical Concrete Specimens[2]

C 42 Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete[2]

C 174 Test Method for Measuring Length of Drilled Concrete Cores[2]

C 192 Practice for Making and Curing Concrete Test Specimens in the Laboratory[2]

C 617 Practice for Capping Cylindrical Concrete Specimens[2]

E 4 Practices for Load Verification of Testing Machines[2]

E 6 Terminology Relating to Methods of Mechanical Testing[3]

E 83 Practice for Verification and Classification of Extensometers[3]

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[2]

3. Significance and Use

3.1 This test method provides a stress to strain ratio value and a ratio of lateral to longitudinal strain for hardened concrete at whatever age and curing conditions may be designated.

3.2 The modulus of elasticity and Poisson's ratio values, applicable within the customary working stress range (0 to 40 % of ultimate concrete strength), may be used in sizing of reinforced and nonreinforced structural members, establishing the quantity of reinforcement, and computing stress for observed strains.

3.3 The modulus of elasticity values obtained will usually be less than moduli derived under rapid load application (dynamic or seismic rates, for example), and will usually be greater than values under slow load application or extended load duration, other test conditions being the same.

4. Apparatus

4.1 *Testing Machine*—Any type of testing machine capable of imposing a load at the rate and of the magnitude prescribed in 6.4 may be used. The machine shall conform to the requirements of Practices E 4 (Constant-Rate of-Traverse CRT-Type Testing Machines section). The spherical head and bearing blocks shall conform to the Apparatus Section of Test Method C 39.

4.2 *Compressometer*[4]—For determining the modulus of elasticity a bonded (Note 1) or unbonded sensing device shall be provided for measuring to the nearest 5 millionths the average deformation of two diametrically opposite gage lines, each parallel to the axis, and each centered about midheight of the specimen. The effective length of each gage line shall be not less than three times the maximum size of the aggregate in the concrete nor more than two thirds the height of the specimen; the preferred length of the gage line is one half the height of the specimen. Gage points may be embedded in or cemented to the specimen, and deformation of the two lines read independently; or a compressometer (such as is shown in Fig. 1) may be used consisting of two yokes, one of which (see B, Fig. 1) is rigidly attached to the specimen and the other (see C, Fig. 1) attached at two diametrically opposite points so that it is free to rotate. At one point on the circumference of the rotating yoke, midway between the two support points, a pivot rod (see A, Fig. 1) shall be used to maintain a constant distance between the two yokes. At the opposite point on the circumference of the rotating yoke, the change in distance between the yokes (that is, the gage reading) is equal to the sum of the displacement due to specimen deformation and the displacement due to rotation of the yoke about the pivot rod (see Fig. 2).

4.2.1 Deformation may be measured by a dial gage used
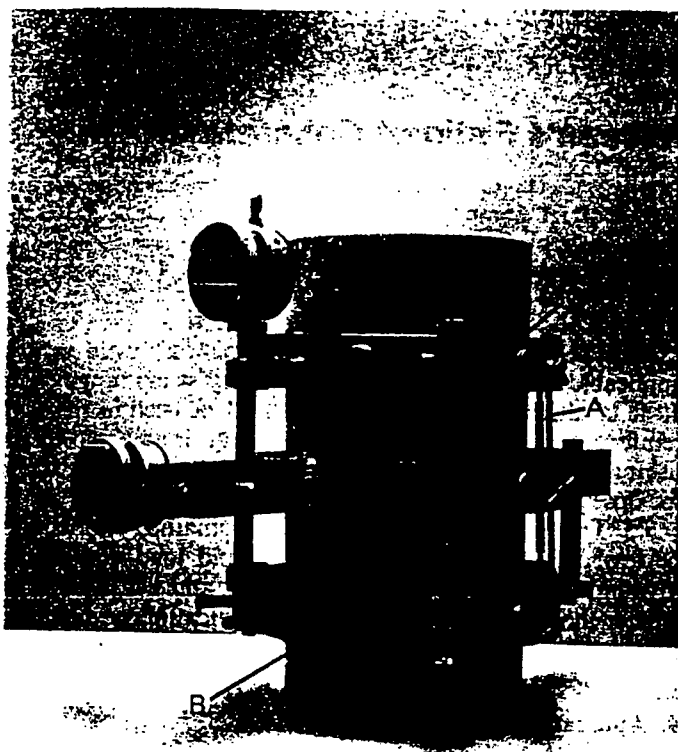
FIG. 1 Suitable Compressometer

d = displacement due to specimen deformation
r = displacement due to rotation of the yoke about the pivot rod
a = location of gage
b = support point of the rotating yoke
c = location of pivot rod
g = gage reading

FIG. 2 Diagram of Displacements

directly or with a lever multiplying system, by a wire strain gage, or by a linear variable differential transformer. If the distances of the pivot rod and the gage from the vertical plane passing through the support points of the rotating yoke are equal, the deformation of the specimen is equal to one-half the gage reading. If these distances are not equal, the deformation shall be calculated as follows:

$$d = ge_r/(e_r + e_g) \qquad (1)$$

where:

d = total deformation of the specimen throughout the effective gage length, μin. (μm),

g = gage reading, μin. (μm),

e_r = the perpendicular distance, measured in inches (millimetres) to the nearest 0.01 in. (0.254 mm) from the pivot rod to the vertical plane passing through the two support points of the rotating yoke, and

e_g = the perpendicular distance, measured in inches (millimetres) to the nearest 0.01 in. (0.254 mm) from the gage to the vertical plane passing through the two support points of the rotating yoke.

Procedures for calibrating strain-measuring devices are given in Practice E 83.

NOTE 1—Although bonded strain gages are satisfactory on dry specimens, they may be difficult, if not impossible, to mount on specimens continually moist-cured until tested.

4.3 *Extensometer*[4]—If Poisson's ratio is desired, the transverse strain shall be determined (1) by an unbonded extensometer capable of measuring to the nearest 25 μin. (0.635 μm) the change in diameter at the midheight of the specimen or (2) by two bonded strain gages (Note 1) mounted circumferentially at diametrically opposite points at the midheight of the specimen and capable of measuring circumferential strain to the nearest 5 millionths. A combined compressometer and extensometer (Fig. 3) is a convenient unbonded device. This apparatus shall contain a third yoke (consisting of two equal segments) located halfway between the two compressometer yokes and attached to the specimen at two diametrically opposite points. Midway between these points a short pivot rod (A', see Fig. 3), adjacent to the long pivot rod, shall be used to maintain a constant distance between the bottom and middle yokes. The middle yoke shall be hinged at the pivot point to permit rotation of the two segments of the yoke in the horizontal plane. At the opposite point on the circumference, the two segments shall be connected through a dial gage or other sensing device capable of measuring transverse deformation to the nearest 50 μin. (1.27 μm). If the distances of the hinge and the gage from the vertical plane passing through the support points of the middle yoke are equal, the transverse deformation of the specimen diameter is equal to one-half the gage reading. If these distances are not equal, the transverse deformation of the specimen diameter may be calculated in accordance with Eq 2.

$$d' = g'e'_h/(e'_h + e'_g) \qquad (2)$$

where:

d' = transverse deformation of the specimen diameter, μin. (μm),

g' = transverse gage reading, μin. (μm),

e'_h = the perpendicular distance, measured in inches (millimeters) to the nearest 0.01 in. (0.254 mm) from the hinge to the vertical plane passing through the support points of the middle yoke, and

e'_g = the perpendicular distance, measured in inches (millimeters) to the nearest 0.01 in. (0.254 mm) from the gage to the vertical plane passing through the support points of the middle yoke.

4.4 *Balance or Scale*, accurate to 0.1 lb (0.045 kg) shall be provided if necessary.

5. Test Specimens

5.1 *Molded Cylindrical Specimens*—Test cylinders shall

be molded in accordance with the requirements for compression test specimens in Practice C 192, or in Practice C 31. Specimens shall be subjected to the specified curing conditions and tested at the age for which the elasticity information is desired. Specimens shall be tested within 1 h after removal from the curing or storage room. Specimens removed from a moist room for test shall be kept moist by a wet cloth covering during the interval between removal and test.

5.2 *Drilled Core Specimens*—Cores shall comply with the requirements for drilling, and moisture conditioning applicable to compressive strength specimens in Test Method C 42, except that only diamond-drilled cores having a length-to-diameter ratio greater than 1.50 shall be used. Requirements relative to storage and to ambient conditions immediately prior to test shall be the same as for molded cylindrical specimens.

5.3 The ends of the test specimens shall be made perpendicular to the axis (±0.5°) and plane (within 0.002 in.). If the specimen as cast does not meet the planeness requirements, planeness shall be accomplished by capping in accordance with Practice C 617, or by lapping, or by grinding. Aggregate popouts which occur at the ends of specimens may be repaired provided the total area of popouts does not exceed 10 % of the specimen area and the repairs are made before capping or grinding is completed (Note 2). Planeness will be considered within tolerance when a 0.002 in. (0.05 mm) feeler gage will not pass between the specimen surface and a straight edge held against the surface.

NOTE 2—Repairs may be made by epoxying the dislodged aggregate back in place or by filling the void with capping material and allowing adequate time for it to harden.

5.4 The diameter of the test specimen shall be measured by caliper to the nearest 0.01 in. (0.25 mm) by averaging two diameters measured at right angles to each other near the center of the length of the specimen. This average diameter shall be used for calculating the cross-sectional area. The length of a molded specimen, including caps, shall be measured and reported to the nearest 0.1 in. (2.54 mm). The length of a drilled specimen shall be measured in accordance with Test Method C 174; the length, including caps, shall be reported to the nearest 0.1 in.

6. Procedure

6.1 Maintain the ambient temperature and humidity as constant as possible throughout the test. Record any unusual fluctuation in temperature or humidity in the report.

6.2 Use companion specimens to determine the compressive strength in accordance with Test Method C 39 prior to the test for modulus of elasticity.

6.3 Place the specimen, with the strain-measuring equipment attached, on the lower platen or bearing block of the testing machine. Carefully align the axis of the specimen with the center of thrust of the spherically-seated upper bearing block. Note the reading on the strain indicators. As the spherically-seated block is brought slowly to bear upon the specimen, rotate the movable portion of the block gently by hand so that uniform seating is obtained.

6.4 Load the specimen at least twice. Do not record any data during the first loading. Base calculations on the average of the results of the subsequent loadings. At least two subsequent loadings are recommended so that the repeatability of
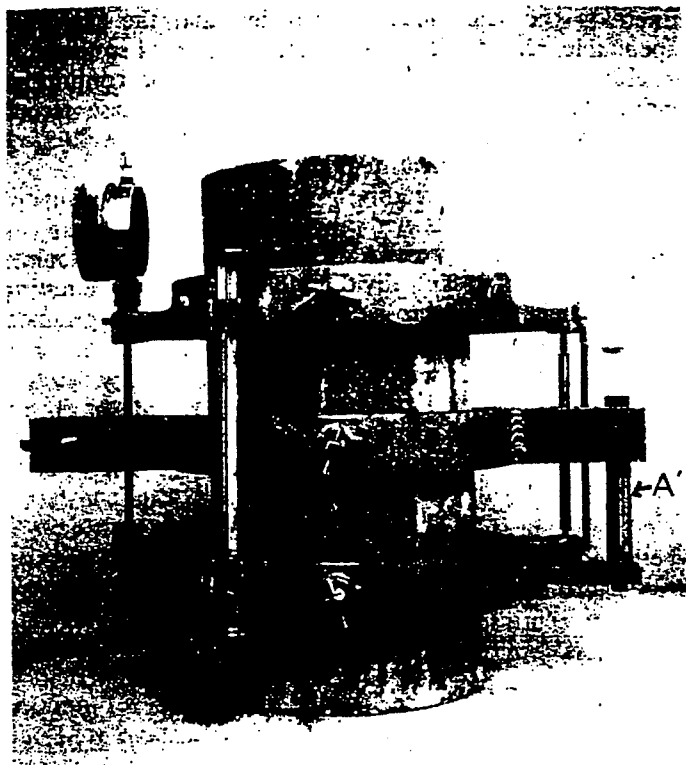
FIG. 3 Suitable Combined Compressometer-Extensometer

the test may be noted. During the first loading, which is primarily for the seating of the gages, observe the performance of the gages (Note 3) and correct any unusual behavior prior to the second loading. Obtain each set of readings as follows: Apply the load continuously and without shock. Set testing machines of the screw type so that the moving head travels at a rate of about 0.05 in. (1.25 mm)/min when the machine is running idle. In hydraulically operated machines, apply the load at a constant rate within the range 35 ± 5 psi (241 ± 34 kPa)/s. Record, without interruption of loading, the applied load and longitudinal strain at the point (*1*) when the longitudinal strain is 50 millionths and (*2*) when the applied load is equal to 40 % of the ultimate load (see 6.5). Longitudinal strain is defined as the total longitudinal deformation divided by the effective gage length. If Poisson's ratio is to be determined, record the transverse strain at the same points. If a stress-strain curve is desired, take readings at two or more intermediate points without interruption of loading; or use an instrument that makes a continuous record. Immediately upon reaching the maximum load, except on the final loading, reduce the load to zero at the same rate at which it was applied. If the observer fails to obtain a reading, complete the loading cycle and then repeat it. Record the extra cycle in the report.

NOTE 3—Where a dial gage is used to measure longitudinal deformation, it is convenient to set the gage before each loading so that the indicator will pass the zero point at a longitudinal strain of 50 millionths.

6.5 The modulus of elasticity and strength may be ob-

tained on the same loading provided that the gages are expendable, removable, or adequately protected so that it is possible to comply with the requirement for continuous loading given in Test Method C 39. In this case record several readings and determine the strain value at 40 % of the ultimate by interpolation.

6.6 If intermediate readings are taken, plot the results of each of the three tests with the longitudinal strain as the abscissa and the compressive stress as the ordinate. Calculate the compressive stress by dividing the quotient of the testing machine load by the cross-sectional area of the specimen determined in accordance with 5.4.

7. Calculation

7.1 Calculate the modulus of elasticity, to the nearest 50 000 psi (344.74 MPa) as follows:

$$E = (S_2 - S_1)/(\epsilon_2 - 0.000050)$$

where:
E = chord modulus of elasticity, psi,
S_2 = stress corresponding to 40 % of ultimate load.
S_1 = stress corresponding to a longitudinal strain, ϵ_1, of 50 millionths, psi, and
ϵ_2 = longitudinal strain produced by stress S_2.

7.2 Calculate Poisson's ratio, to the nearest 0.01, as follows:

$$\mu = (\epsilon_{t2} - \epsilon_{t1})/(\epsilon_2 - 0.000050)$$

where:
μ = Poisson's ratio,
ϵ_{t2} = transverse strain at midheight of the specimen produced by stress S_2, and
ϵ_{t1} = transverse strain at midheight of the specimen produced by stress S_1.

8. Report

8.1 Report the following information:
8.1.1 Specimen identification number,
8.1.2 Dimensions of specimen, in inches (or millimetres),
8.1.3 Curing and environmental histories of the specimen
8.1.4 Age of the specimen,
8.1.5 Strength of the concrete, if determined,
8.1.6 Unit weight of the concrete, if determined,
8.1.7 Stress-strain curves, if plotted,
8.1.8 Chord modulus of elasticity, and
8.1.9 Poisson's ratio, if determined.

9. Precision and Bias

9.1 *Precision*—The single-operator-machine multibatch precision is ±4.25 % (R1S %) max, as defined in Practice E 177, over the range from 2.5 to 4 × 10^6 psi (17.3 to 27.6 × 10^9 Pa); therefore, the results of tests of duplicate cylinders from different batches should not depart more than 5 % from the average of the two.

9.2 *Bias*—This test method has no bias because the values determined can only be defined in terms of the test method.

Standard Test Method for
Creep of Concrete in Compression[1]

This standard is issued under the fixed designation C 512; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the creep of molded concrete cylinders subjected to sustained longitudinal compressive load. This test method is limited to concrete in which the maximum aggregate size does not exceed 2 in. (50 mm).

1.2 The values stated in inch-pound units are to be regarded as the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 39 Test Method for Compressive Strength of Cylindrical Concrete Specimens[2]

C 192 Practice for Making and Curing Concrete Test Specimens in the Laboratory[2]

C 470 Specification for Molds for Forming Concrete Test Cylinders Vertically[2]

C 617 Practice for Capping Cylindrical Concrete Specimens[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

3. Significance and Use

3.1 This test method measures the load-induced time-dependent compressive strain at selected ages for concrete under an arbitrary set of controlled environmental conditions.

3.2 This test method can be used to compare creep potentials of different concretes. A procedure is available, using the developed equation (or graphical plot), for calculating stress from strain data within massive non-reinforced concrete structures. For most specific design applications, the test conditions set forth herein must be modified to more closely simulate the anticipated curing, thermal, exposure, and loading age conditions for the prototype structure. Current theories and effects of material and environmental

parameters are presented in ACI SP-9, Symposium on Creep of Concrete.[3]

3.3 In the absence of a satisfactory hypothesis governing creep phenomena, a number of assumptions have been developed that have been generally substantiated by test and experience.

3.3.1 Creep is proportional to stress from 0 to 40 % of concrete compressive strength.

3.3.2 Creep has been conclusively shown to be directly proportional to paste content throughout the range of paste contents normally used in concrete. Thus the creep characteristics of concrete mixtures containing aggregate of maximum size greater than 2 in. (50 mm) may be determined from the creep characteristics of the minus 2-in. (minus 50-mm) fraction obtained by wet-sieving. Multiply the value of the characteristic by the ratio of the cement paste content (proportion by volume) in the full concrete mixture to the paste content of the sieved sample.

3.4 The use of the logarithmic expression (Section 8) does not imply that the creep strain-time relationship is necessarily an exact logarithmic function; however, for the period of one year, the expression approximates normal creep behavior with sufficient accuracy to make possible the calculation of parameters that are useful for the purpose of comparing concretes.

3.5 There are no data that would support the extrapolation of the results of this test to tension or torsion.

4. Apparatus

4.1 *Molds*—Molds shall be cylindrical conforming to the provisions of Practice C 192, or to the provisions of Specification C 470. If required, provisions shall be made for attaching gage studs and inserts, and for affixing integral bearing plates to the ends of the specimen as it is cast.

4.1.1 Horizontal molds shall conform to the requirements of the section on horizontal molds for creep test cylinders of Practice C 192. A horizontal mold that has proven satisfactory is shown in Fig. 1.

4.2 *Loading Frame*, capable of applying and maintaining the required load on the specimen, despite any change in the dimension of the specimen. In its simplest form the loading frame consists of header plates bearing on the ends of the loaded specimens, a load-maintaining element that may be either a spring or a hydraulic capsule or ram, and threaded rods to take the reaction of the loaded system. Bearing surfaces of the header plates shall not depart from a plane by more than 0.001 in. (0.025 mm). In any loading frame.

FIG. 1 Horizontal Mold for Creep Specimens

6 x 3 IN. (OR 150 x 75 MM) PLUG (CONCRETE)

UPPER JACK PLATE
LOAD BARS
LOWER JACK PLATE
UPPER LOAD PLATE

C = 6 x 12 IN. (OR 150 x 300 MM) TEST CYLINDERS

6 x 3 IN. (OR 150 x 75 M'M) PLUG (CONCRETE)

LOWER LOAD PLATE
UPPER BASE PLATE
SPRINGS
LOWER BASE PLATE

FIG. 2 Spring-Loaded Creep Frame

several specimens may be stacked for simultaneous loading. The length between header plates shall not exceed 70 in. (1780 mm). When a hydraulic load-maintaining element is used, several frames may be loaded simultaneously through a central hydraulic pressure-regulating unit consisting of an accumulator, a regulator. indicating gages, and a source of high pressure, such as a cylinder of nitrogen or a high-pressure pump. Springs such as railroad car springs may be used to maintain the load in frames similar to those described above: the initial compression shall be applied by m⁻⁻ns of a portable jack or testing machine. When springs sed, care should be taken to provide a spherical head or ball joint, and end plates rigid enough to ensure uniform loading of the cylinders. Figure 2 shows an acceptable spring-loaded frame. Means shall be provided for measuring the load to the nearest 2 % of total applied load. This may be a permanently installed hydraulic pressure gage or a hydraulic jack and a load cell inserted in the frame when the load is applied or adjusted.

4.3 *Strain-Measuring Device*—Suitable apparatus shall be provided for the measurement of longitudinal strain in the specimen to the nearest 10 millionths. The apparatus may be embedded, attached, or portable. If a portable apparatus is used, gage points shall be attached to the specimen in a positive manner. Attached gages relying on friction contact are not permissible. If an embedded device is used, it shall be situated so that its strain movement occurs along the longitudinal axis of the cylinder. If external devices are used, strains shall be measured on not less than two gage lines spaced uniformly around the periphery of the specimen. The gages may be instrumented so that the average strain on all gage lines can be read directly. The effective gage length shall be at least three times the maximum size of aggregate in the concrete. The strain-measuring device shall be capable of measuring strains for at least 1 year without change in calibration.

NOTE 1—Systems in which the varying strains are compared with a ⁻⁻nstant-length standard bar are considered most reliable. but unbonded ..trical strain gages are satisfactory.
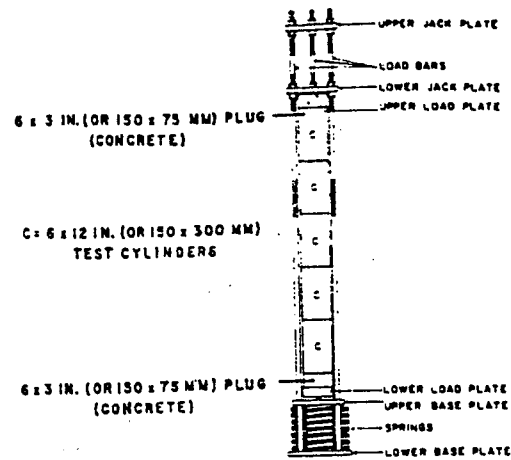
5. Test Specimens

5.1 *Specimen Size*—The diameter of each specimen shall be 6 ± ¹⁄₁₆ in. (or 150 ± 1.6 mm), and the length shall be at least 11½ in. (292 mm). When the ends of the specimen are in contact with steel bearing plates, the specimen length shall be at least equal to the gage length of the strain-measuring apparatus plus the diameter of the specimen. When the ends of the specimen are in contact with other concrete specimens similar to the test specimen, the specimen length shall be at least equal to the gage length of the strain-measuring apparatus plus 1½ in. (38 mm). Between the test specimen and the steel bearing plate at each end of a stack, a supplementary noninstrumented cylinder whose diameter is equal to that of the test cylinders and whose length is at least half its diameter shall be installed.

5.2 *Fabricating Specimens*—The maximum size of aggregate shall not exceed 2 in. (50-mm) (Section 3). Vertically cast cylinders shall be fabricated in accordance with the provisions of Practice C 192. The ends of each cylinder shall meet the planeness requirements described in the scope of Practice C 617 (Note 2). Horizontally cast specimens shall be consolidated by the method appropriate to the consistency of the concrete as indicated in the methods of consolidation section of Practice C 192. Care must be taken to ensure that the rod or vibrator does not strike the strain meter. When vibration is used, the concrete shall be placed in one layer and the vibrating element shall not exceed 1¼ in. (32 mm) in diameter. When rodding is used, the concrete shall be placed in two approximately equal layers and each layer shall be rodded 25 times evenly along each side of the strain meter. After consolidation the concrete shall be struck off with trowel or float, then trowelled the minimum amount to form the concrete in the opening concentrically with the rest of the specimen. A template curved in the radius of the specimen may be used as a strikeoff to shape and finish the concrete more precisely in the opening. When cylinders are to be stacked, lapping of ends is strongly recommended.

NOTE 2—Requirements for planeness may be met by capping. lapping. or, at the time of casting. fitting the ends with bearing plates normal to the axis of the cylinder.

5.3 *Number of Specimens*—No fewer than six specimens (Note 3) shall be made from a given batch of concrete for each test condition; two shall be tested for compressive strength, two shall be loaded and observed for total deformation, and two shall remain unloaded for use as controls to indicate deformations due to causes other than load. Each strength and control specimen shall undergo the same curing and storage treatment as the loaded specimen.

NOTE 3—It is recommended that specimens be tested in triplicate although duplicate specimens are acceptable.

6. Curing and Storage of Specimens

6.1 *Standard Curing*—Before removal from the molds, specimens shall be stored at 73.4 ± 3.0°F (23.0 ± 1.7°C) and covered to prevent evaporation. The specimens shall be removed from the molds not less than 20 nor more than 48 h after molding and stored in a moist condition at a temperature of 73.4 ± 3.0°F until the age of 7 days. A moist condition is that in which free water is maintained on the surfaces of the specimens at all times. Specimens shall not be exposed to a stream of running water nor be stored in water. After the completion of moist curing the specimens shall be stored at a temperature of 73.4 ± 2.0°F (23.0 ± 1.1°C) and at a relative humidity of 50 ± 4 % until completion of the test.

6.2 *Basic Creep Curing*—If it is desired to prevent the gain or loss of water during the storage and test period, specimens shall at the time of fabrication or stripping be enclosed and sealed in moistureproof jackets (for example, copper or butyl rubber) to prevent loss of moisture by evaporation and shall remain sealed throughout the period of storage and testing.

6.3 *Variable Curing Temperature Regimen*—When it is desired to introduce the effect of temperature on the elastic and inelastic properties of a concrete (as. for example, the adiabatic temperature conditions existing in massive concrete or temperature conditions to which concrete is subjected during accelerated curing), temperatures within the specimen storage facility shall be controlled to correspond to the desired temperature history. The user shall be responsible for establishing the time-temperature history to be followed and the permissible range of deviation therefrom.

6.4 *Other Curing Conditions*—Other test ages and ambient storage conditions may be substituted when information is required for specific applications. The storage conditions shall be carefully detailed in the report.

7. Procedure

7.1 *Age at Loading*—When the purpose of the test is to compare the creep potential of different concretes, initially load the specimens at an age of 28 days. When the complete creep behavior of a given concrete is desired, prepare the specimens for initial loading in the following ages: 2, 7, 28, and 90 days, and 1 year. If information is desired for other ages of loading, include the age in the report.

7.2 *Loading Details*—Immediately before loading the creep specimens. determine the compressive strength of the strength specimens in accordance with Test Method C 39. At the time unsealed creep specimens are placed in the loading frame. cover the ends of the control cylinders to prevent loss of moisture (Note 4). Load the specimens at an intensity of not more than 40 % of the compressive strength at the age of

loading. Take strain readings immediately before and after loading, 2 to 6 h later, then daily for 1 week, weekly until the end of 1 month, and monthly until the end of 1 year. Before taking each strain reading, measure the load. If the load varies more than 2 % from the correct value, it must be adjusted (Note 5). Take strain readings on the control specimens on the same schedule as the loaded specimens.

NOTE 4—In placing creep specimens in the frame, take care in aligning the specimens to avoid eccentric loading. When cylinders are stacked and external gages are used, it may be helpful to apply a small preload such that the resultant stress does not exceed 200 psi (1380 kPa) and note the strain variation around each specimen, after which the load may be removed and the specimens realigned for greater strain uniformity.

NOTE 5—Where springs are used to maintain the load, the adjustment can be accomplished by applying the correct load and tightening the nuts on the threaded reaction rods.

8. Calculation

8.1 Calculate the total load-induced strain per pound per square inch (or kilopascal) at any time as the difference between the average strain values of the loaded and control specimens divided by the average stress. To determine creep strain per pound-force per square inch (or kilopascal) for any age, subtract from the total load-induced strain per pound-force per square inch (or kilopascal) at that age the strain per pound-force per square inch (or kilopascal) immediately after loading. If desired, plot total strain per pound-force per square inch (or kilopascal) on semilog coordinate paper, on which the logarithmic axis represents time, to determine the constants $1/E$ and $F(K)$ for the following equation:

$$\epsilon = (1/E) + F(K)\ln(t + 1)$$

where:
ϵ = total strain psi (or kPa),
E = instantaneous elastic modulus. psi (or kPa),
$F(K)$ = creep rate. calculated as the slope of a straight line representing the creep curve on the semilog plot. and
t = time after loading, days.

The quantity $1/E$ is the initial elastic strain per pound per square inch (or kilopascal) and is determined from the strain readings taken immediately before and after loading the specimen. If loading was not accomplished expeditiously. some creep may have occurred before the after-loading strain was observed, in which event extrapolation to zero time by the method of least squares may be used to determine this quantity.

9. Report

9.1 Report the following information:
9.1.1 Cement content, water-cement ratio, maximum aggregate size. slump, and air content,
9.1.2 Type and source of cement. aggregate. admixture. and mixing water (if other than fresh water is used),
9.1.3 Position of cylinder when cast.
9.1.4 Storage conditions prior to and subsequent to loading,
9.1.5 Age at time of loading.
9.1.6 Compressive strength at age of loading.
9.1.7 Type of strain measuring device.
9.1.8 Magnitude of any preload.

9.1.9 Intensity of applied load,

9.1.10 Initial elastic strain,

9.1.11 Creep strain per pound per square inch (or kilopascal) at designated ages up to 1 year, and

9.1.12 Creep rate, $F(K)$, if determined.

10. Precision and Bias

10.1 *Precision*—The single-operator single-batch coefficient of variation has been found to be 4.0 %[A], and the single-operator-multi-batch coefficient of variation has been found to be 9.0 %[A], over the range of creep strains from 250 to 2000 millionths. The results of two properly conducted tests by the same operator on the same material should not differ by more than 6 %[B] of their average. The results of two properly conducted tests by the same operator on material cast from different batches should not differ by more than 13 %[B] of their average.

10.2 *Bias*—This test method has no bias because the values determined can only be defined in terms of the test method.

11. Keywords

11.1 compression; concrete; creep; creep strain; elastic strain

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[A] These numbers represent the (1s %) limit as described in Practice C 670.

[B] These numbers represent the (d2s %) limit as described in Practice C 670.